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The Relationship between Plantar Fascia Thickness, Metatarsophalangeal Joint Position and Gender

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The Relationship between Plantar Fascia Thickness, Metatarsophalangeal Joint Position and Gender

by

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A Dissertation submitted in partial satisfaction of
the requirements for the degree
Doctor of Philosophy in Rehabilitation Science

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Each person whose signature appears below certifies that this dissertation in his/her opinion is adequate, in scope and quality, as a dissertation for the degree Doctor of Philosophy.

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ABBREVIATIONS

ANOVA	Analysis of variance
BMI	Body mass index
CI	Confidence interval
Max	Maximum
MRI	Magnetic resonance imaging
MTP	Metatarsophalangeal
SD	Standard deviation

ABSTRACT OF THE DISSERTATION

The Relationship between Plantar Fascia Thickness, Metatarsophalangeal Joint Position and Gender

by

Michael J. Granado

Doctor of Philosophy, Graduate Program in Rehabilitation Science
Loma Linda University, June 2018
Dr. Everett B. Lohman III, Chairperson

Ultrasound is a widely used diagnostic tool for patients with plantar fasciitis. It provides an inexpensive and noninvasive method for quantifying the plantar fascia with accuracy levels comparable to magnetic resonance imaging (MRI). However, some researchers have criticized the lack of standardization in the ultrasound measurement process for plantar fascia thickness as it calls into question the validity of the final measures. One critical component lacking any standardization during the procedure is metatarsophalangeal (MTP) joint position as ultrasound examiners often extend the toe position during the process. This variation has made it difficult to understand the etiology of plantar fasciitis and to identify risk factors, such as gender. The purpose of this study was to investigate and compare the influence of MTP joint extension position on plantar fascia thickness in healthy participants and those with unilateral plantar fasciitis, as well make gender comparisons while controlling for MTP joint position. The plantar fascia thickness of forty participants (20 with unilateral plantar fasciitis and 20 control) was measured via ultrasound three times at three different MTP joint positions: 1) at rest, 2) 30° of extension from the plantar surface, and 3) maximal extension possible. The plantar fascia became significantly thinner as MTP joint extension increased in both the plantar

fasciitis group ($p<0.001$) and the control group ($p<0.001$). When comparing gender differences, males in the plantar fasciitis group had a significantly thicker plantar fascia when compared to female counterparts ($P=0.048$). However, no significant differences were observed between healthy males and females. The results from the study highlight the need to standardize the position of the MTP joints during measurement of plantar fascia thickness. As well, healthy males and females first begin with very similar plantar fascia thickness levels. However, as the onset of plantar fasciitis develops, males tend to exhibit thicker plantar fasciae than their female counterparts.

CHAPTER ONE

INTRODUCTION

The plantar fascia is a flat band of connective tissue residing in the sole of the foot with attachments from the medial tubercle of the calcaneus to the proximal phalanges. If excessive and repetitive tensile forces are imposed onto the plantar fascia, microtrauma eventually develops, a condition known as plantar fasciitis.[27,44,50] It has been reported that 10% of the United States population will develop plantar fasciitis at some point in their lifetime.[13] Despite the prevalence of this condition, very little is still known about its etiology.[30,32] Furthermore, while the diagnosis is often made through a clinical history and physical examination backed by imaging,[17,28] no gold standard for diagnosing plantar fasciitis currently exists.[26,34,41]

Literature Review

Plantar Fascia Thickness and Metatarsophalangeal Joint Extension Position

The first report of ultrasound being used to measure plantar fascia thickness was published in 1992,[20] followed the subsequent year with the first peer-reviewed study.[48] Since then, ultrasound has emerged as a tool for visualizing the plantar fascia with the general consensus found in many studies being that a plantar fascia thickness over 4 mm is consistent with plantar fasciitis.[33,42,48] More recently, ultrasound has even been used to monitor the effectiveness of various plantar fasciitis treatments by observing the thickness reduction of afflicted plantar fasciae.[31,33,35]

However, some authors have argued that a lack of standardization during the thickness measurement process of the plantar fascia has made it a challenge to validate

the 4 mm thickness reference as a guideline consistent with plantar fasciitis.[23,36] An example of this lack of standardization is that the positioning the metatarsophalangeal (MTP) joint during the ultrasound procedure has never been developed. The European Society of Musculoskeletal Radiology published its procedural recommendations for how plantar fascia thickness should be measured.[6] However, a recommendation for how the toes should be positioned during the examination is noticeably absent. While some examiners leave the toes in a resting position, others advocate extending the toes to improve the border definition of the plantar fascia during the procedure.[8,9,23,39] Unfortunately, it is unclear if extending the toes can alter the acquired ultrasound measurements. The average plantar fascia thickness in healthy subjects has been reported in the literature to be between 2.6 and 3.9 mm.[3,19,24,37,39,42,48,49] This relatively large range is most likely due to the discrepancies within the current methodology, as well as subject variation.[39]

The lack of clarity in the literature regarding plantar fascia thickness has continued when comparing plantar fasciae in healthy individuals with asymptomatic plantar fasciae in those with unilateral plantar fasciitis. Some studies have reported no significant difference between the two groups,[3,48] while other studies have reported the asymptomatic plantar fasciae in those with unilateral plantar fasciitis being thicker.[47,51] The importance of studying the asymptomatic plantar fasciae in those with unilateral plantar fasciitis is that bilateral plantar fasciitis has been reported in 13% to 30% of the cases.[28,29] Thus, it may be reasonable to observe a slightly thicker asymptomatic plantar fascia in those with unilateral plantar fasciitis.

Several studies that have demonstrated an increase in plantar fascia tension[10-12] and a rise in the medial longitudinal arch[11,25] as a result of MTP joint extension. In addition, Garcia et al[18] who found that MTP joint extension results in an increase in plantar soft tissue stiffness along with a concomitant decrease in overall plantar soft tissue thickness. Cumulatively, these studies strongly suggest that MTP joint extension could influence measures of plantar fascia thickness.

Plantar Fascia Thickness Differences Between Healthy Males and Females

The relationship of gender and plantar fascia thickness has always been inconsistent in the literature. Previous studies have either found no difference in plantar fascia thickness between males and females,[17,23,37,48] while other studies have identified males as having thicker plantar fasciae when compared to females.[2,23,45] Huerta and Garcia found males had increased plantar fascia thickness when measured 1 cm proximal to the plantar fascia insertion, whereas they found no difference amongst males and females when the thickness was measured at the insertion (i.e., anterior border of the calcaneus where the plantar fascia just leaves the calcaneal tuberosity), 1 cm or 2 cm distal to insertion.[23] While Huerta and Garcia found the plantar fascia thickness to vary by gender depending where along the plantar fascia the thickness was measured, it was indicated in their methodology that they occasionally dorsiflexed the toes during their examination. To what degree the toes were extended, how many participants, and during what locations on the plantar fascia when thickness was measured were all concepts not clarified in their study that could had affected their results. Thus, it is suspected that the

variability of the toe positioning during ultrasound measurements could be a reason why plantar fascia thickness comparisons between males to females have been inconsistent.

Plantar Fasciitis and Gender

It has often been reported anecdotally that women have a higher susceptibility to developing plantar fasciitis.[4,37,44] In fact, evidence can be found to support the implication that plantar fasciitis is more common in either males or females.[14,16,21,29,38,43,46] While the relationship between gender and plantar fasciitis has always been historically unclear, more recent research has suggested that plantar fasciitis is more prevalent in females than males.[16,21,40] Furthermore, the studies reporting males as being more susceptible to plantar fasciitis had some potential flaws. In the study by Lapides and Guidotti who found men to be more likely to develop plantar fasciitis, their study population may had been biased since the study was published in the 1960s and did not include women from a fully integrated industry and weightbearing work force.[29] Other authors have commented on this flaw, as well.[5,14,15] In another study that found men more likely to develop plantar fasciitis, Taunton et al speculated that another pathological variable may had not been accounted for that influenced their results.[46] While foot pain in general has been reported to be more common in women in large population-based studies,[22,36] the exact reasons, especially regarding plantar fasciitis have yet to be identified. Some have suggested that the architecture and mechanical properties of the plantar fascia in women differing with that of men as a possible cause.[40] Women have also been observed to utilize healthcare services more than men,[7] which could possibly explain higher percentages of women being diagnosed with plantar fasciitis in various medical databases.[16] Nevertheless, the

evidence supporting the view that women are more at risk for plantar fasciitis is mounting.[14,16,21,38,43] If women are more likely to develop plantar fasciitis, it could be hypothesized that they would exhibit a thicker plantar fascia when compared to males. However, no known study to us has corroborated that concept.

Statement of Purpose

The purpose of this study was to investigate and compare the influence of three different MTP joint extension positions on plantar fascia thickness via ultrasound in: 1) healthy participants and those with unilateral plantar fasciitis, 2) males and females both healthy and with unilateral plantar fasciitis.

Hypothesis

We tested the general hypothesis that the thickness of the plantar fascia would decrease as the MTP joints were extended in all groups regardless of the health status of the plantar fascia and gender. We predicted the following would be observed in our study:

1. Plantar fascia thickness would be significantly thinner in both the plantar fasciitis and control groups when MTP joints were extended from at rest to the maximum end of range.
2. Plantar fascia thickness would be significantly thicker in the plantar fasciitis group at all three MTP joints extension positions when compared to the control group.

3. Plantar fascia thickness in healthy males will be thicker at all three MTP joint extension positions when compared to healthy females.
4. Plantar fascia thickness in females with unilateral plantar fasciitis will be thicker at all three MTP joint extended positions when compared to males with unilateral plantar fasciitis.

CHAPTER TWO

METATARSOPHALANGEAL JOINT EXTENSION CHANGES ULTRASOUND MEASUREMENTS FOR PLANTAR FASCIA THICKNESS

by

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Abstract

Ultrasound is an inexpensive method for quantifying plantar fascia thickness, especially in those with plantar fasciitis. Ultrasound has also been used to assess the effectiveness of various treatments for plantar fasciitis by comparing plantar fascia thickness before and after an intervention period. While a plantar fascia thickness over 4 mm via ultrasound has been proposed to be consistent with plantar fasciitis, some researchers believe the 4 mm plantar fascia thickness level to be a dubious guideline for diagnosing plantar fasciitis due to the lack of standardization of the measurement process for plantar fascia thickness. In particular, no universal guidelines exist on the positioning of the metatarsophalangeal (MTP) joints during the procedure and the literature also has inconsistent protocols. The purpose of this study is to investigate and compare the influence of MTP joint extension on plantar fascia thickness in healthy participants and those with unilateral plantar fasciitis. The plantar fascia thickness of forty participants (20 with unilateral plantar fasciitis and 20 control) was measured via ultrasound three times at three different MTP joint positions: 1) at rest, 2) 30° of extension from the plantar surface, and 3) maximal extension possible. The plantar fascia became significantly thinner as MTP joint extension increased in both the plantar fasciitis group ($p<0.001$) and the control group ($p<0.001$). In the plantar fasciitis group, the involved plantar fascia was 1.2 to 1.3 mm thicker ($p<0.001$) than the uninvolved side depending on the MTP joint position. In the control group, the difference in plantar fascia thickness between the two sides was less than 0.1 mm ($p<0.92$) at any MTP joint position. MTP joint position can influence the ultrasound measurement of plantar fascia thickness. It is recommended that plantar fascia thickness measurements be performed with the toes at rest. If MTP joints

must be extended, then the toes should be extended maximally and then noted to ensure subsequent ultrasound procedures are repeated. Standardizing the position of the MTP joints is not only important for attaining the most accurate thickness measurement of the plantar fascia, but is also important to researchers who use plantar fascia thickness to determine the effectiveness of various plantar fasciitis interventions.

Key Words: Fasciitis, Fasciosis, Fasciopathy, Windlass, Toe Dorsiflexion, Ultrasonography, Treatment

Introduction

The plantar fascia is a flat band of connective tissue residing in the sole of the foot with attachments from the medial tubercle of the calcaneus to the proximal phalanges.[31] If excessive and repetitive tensile forces are imposed onto the plantar fascia, presumed development of microtrauma results in a condition known as plantar fasciitis.[10,36] In the United States, approximately one million outpatient visits for plantar fasciitis were made annually during 1995-2000.[29] It was also estimated that in 2007, the cost to treat plantar fasciitis was between 192 and 376 million US dollars.[32] Despite the pervasiveness of this condition, no gold standard exists for diagnosing plantar fasciitis, although the diagnosis is often made through a clinical history and physical examination backed by imaging.[17,28]

Ultrasound is a widely used tool especially in conjunction with plantar fasciitis because it provides an inexpensive, and noninvasive method for quantifying the plantar fascia with accuracy levels comparable to magnetic resonance imaging (MRI).[1,30] Several studies agree that a plantar fascia thickness over 4 mm via ultrasound is consistent with plantar fasciitis.[2,3,23,33,34] However, some researchers have argued that a lack of standardization in the measurement process for plantar fascia thickness makes it challenging to properly validate the 4 mm reference guideline.[14,17] One critical component for standardizing measurement procedures is a thorough characterization of the relationship between plantar fascia thickness and toe position.

Several studies that have demonstrated an increase in plantar fascia tension[7-9] and a rise in the medial longitudinal arch[8,16] as a result of metatarsophalangeal (MTP) joint extension. In addition, Garcia et al[12] who found that MTP joint extension results in an increase in plantar soft tissue stiffness along with a concomitant decrease in overall

plantar soft tissue thickness. Cumulatively, these studies strongly suggest that MTP joint extension could influence measures of plantar fascia thickness. Yet, guidelines for positioning the MTP joint during ultrasound measurements of the plantar fascia have not been developed. For example, the European Society of Musculoskeletal Radiology has produced its procedural recommendations for how the plantar fascia thickness should be measured,[22] but a recommendation for how the toes should be positioned during the examination is noticeably absent. While many ultrasound studies measuring plantar fascia thickness either leave the toes in a resting position or do not even indicate the position of the toes during the examination, other authors have advocated extending the toes to improve the border definition of the plantar fascia during the procedure.[5,6,14,27,33] However, it is unclear if doing so alters the acquired ultrasound measurements.

The purpose of this study was to investigate the influence of active MTP joint extension on plantar fascia thickness. Since the ultrasound procedure is often performed in those with plantar fasciitis, a comparison between plantar fasciae in those with unilateral plantar fasciitis with healthy control participants was also conducted in the study. More specifically, the objectives of this study were: 1) examine the changes in plantar fascia thickness by MTP joint extension position and side (i.e., involved versus uninvolved) in the plantar fasciitis group; 2) examine changes in plantar fascia thickness by MTP joint extension position and side (right versus left) in the control group; and 3) compare changes in plantar fascia thickness by MTP joint extension position in the uninvolved side of the plantar fasciitis group with the control group. We hypothesized that the thickness of the plantar fascia would decrease in both groups studied as MTP joint extension is increased.

Materials and Methods

Participants

All participants signed an informed consent, and the study was approved by the Loma Linda University Human Research Participant Protection (HRPP) Program/Institutional Review Board (Approval No. 5150186**)**. Participants with plantar fasciitis were required to exhibit the classic symptoms of plantar fasciitis (i.e., plantar heel tenderness, morning pain with the first few steps out of bed) and have had symptoms persisting longer than 6 weeks to ensure participants were not in an acute phase of the condition. Individuals were excluded from the study if they had any neurologic, systemic inflammatory, metabolic, connective tissue, or inner-ear disorders. Those with severe toe deformities, trauma/surgery to the lumbar spine or lower extremities, an antalgic gait pattern, a cortisone injection over the preceding three months, or recent consumption of balance-altering medication were also excluded from the study.

Measurement of Plantar Fascia Thickness

Sagittal thickness of the plantar fascia was measured with a 13-6 MHz linear array transducer (Sonosite M-Turbo Ultrasound System, Bothell, WA, USA) and acoustic coupling gel applied onto the plantar surface of the heel. Participants were positioned in prone with the examined foot over the edge of the examination table and the ankle in neutral. The transducer was positioned over the plantar surface of the heel approximately 0.5 cm medial to the midline longitudinal axis of the foot in order to visualize a longitudinal view of the plantar fascia. The thickness of the plantar fascia was then measured at the anterior margin of the calcaneus (Figure 1).

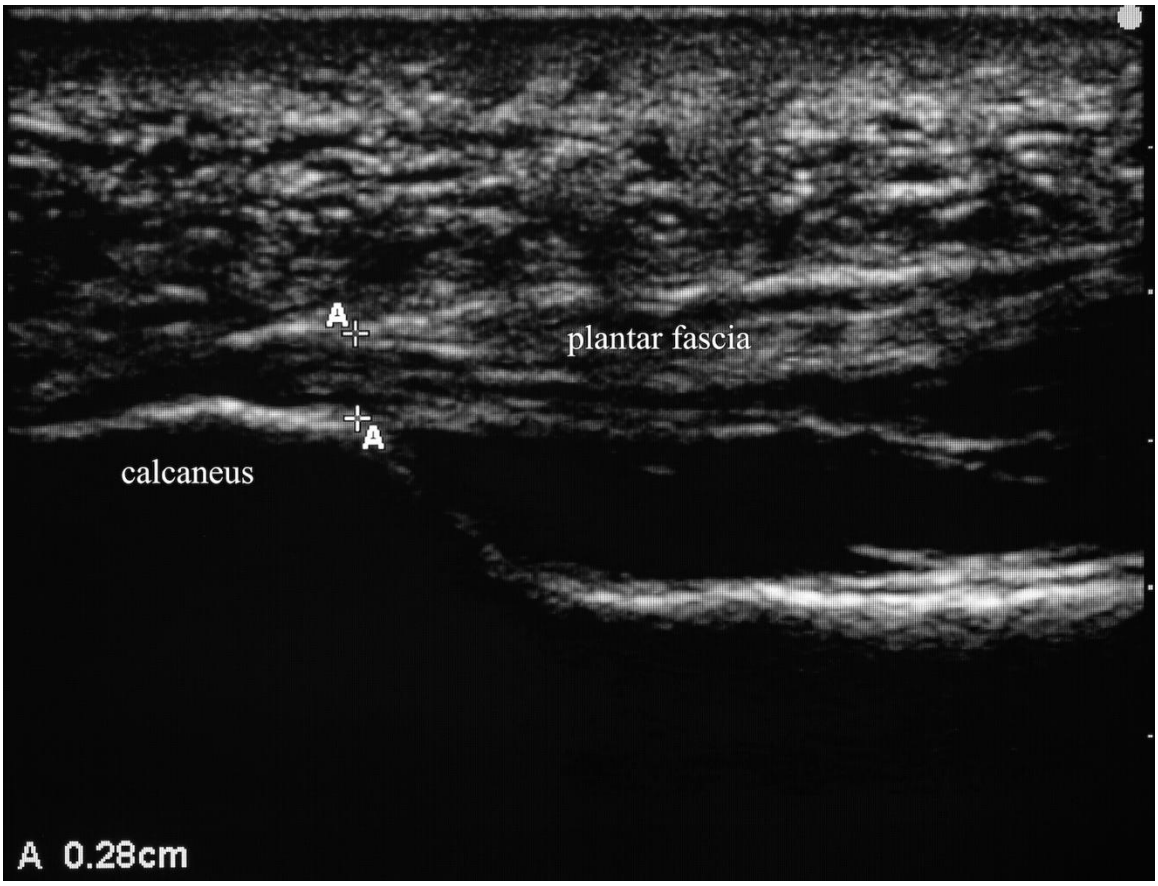

Figure 1. Longitudinal sonogram of the plantar fascia with the thickness being measured at the anterior margin of the calcaneus.

The ultrasound measurement was performed with the toes in three different MTP joint positions: 1) at rest, 2) 30° of active extension from the plantar surface, and 3) maximal extension actively possible by the participant (Figure 2). All of the toes were extended passively together to the desired position by the examiner whereby the participant was then asked to actively hold the position while the examiner continued to monitor for any movement. Goniometry was only performed when the MTP joints were extended to 30° as measurement was not necessary in the at rest or max extension positions. Measurement of first MTP joint extension was performed on the medial aspect of the foot with the proximal arm of the goniometer parallel with the plantar surface of

the foot and the distal arm aligned with the midline of the proximal phalanx of the first toe. The traditional method for measuring extension at the first MTP joint involves aligning the proximal arm of the goniometer with first metatarsal, either dorsally or over the medial surface of the foot rather than the plantar surface of the foot.[25] A modification was employed in an effort to make comparisons between feet from different individuals more reliable as outlined by Allen and Gross.[4] In the foot-flat position, the MTP joints are typically extended 20° from the midline of the metatarsals.[21] However, it was felt that different foot types could result in the first metatarsal having a variable position. The plantar surface of the foot being fixed would not suffer from this inconsistency and would allow for a "standard" position in between the two other MTP joint positions (i.e., at rest and at max extension). When at rest and at max extension, a specific joint angle was not necessary, which was why goniometry was not performed. Ultrasound measurements conducted with the MTP joints at rest were intended to place the least amount of tension onto the plantar fascia, whereas maximal MTP joint extension was necessary to apply the most amount of tension. A standard MTP joint position during the initial and final conditions of ultrasound measurements would had most likely resulted in relative inaccurate tissue tension in some participants (i.e., presence of unwanted plantar fascia tension at the initial position or inadequate plantar fascia tension when the MTP joints were extended maximally).

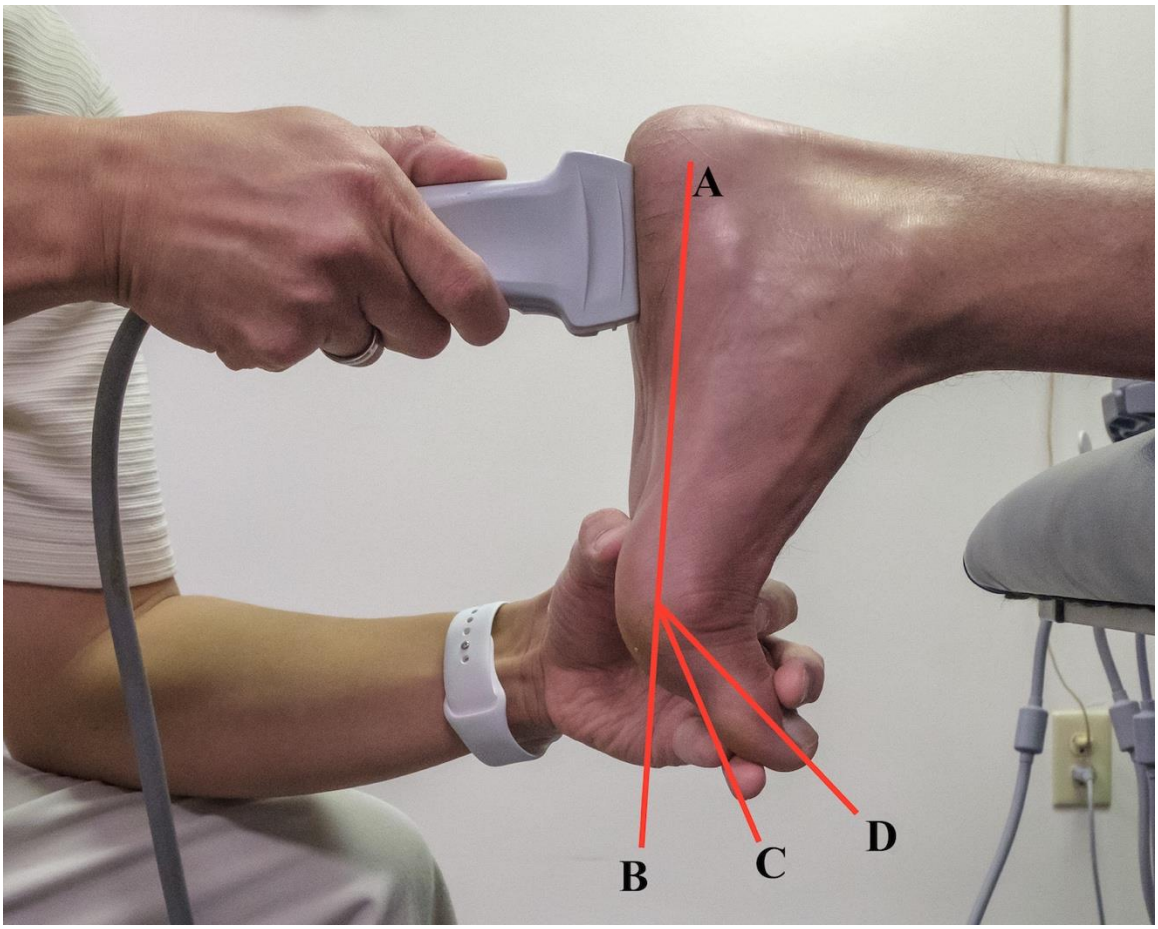

Figure 2. An illustration of the three metatarsophalangeal (MTP) joint extension positions employed during the ultrasound measurement for plantar fascia thickness: (A) plantar surface of the foot; (B) at rest; (C) 30° relative to the plantar surface of the foot; (D) max extension possible

The ultrasound examinations were performed by one licensed physical therapist with sixteen years of clinical experience and who had completed several continuing education radiology courses. However, the examiner had no previous experience in using ultrasound for imaging purposes. Crofts et al[11] demonstrated that relatively new ultrasound examiners with minimal, but structured training could still acquire reliable ultrasound data. Thus prior to the study, the examiner met with a certified ultrasound technician for four instructional sessions over the course of one month to become familiar

with the equipment and technique. During the study, the examiner was blind to which foot was afflicted with plantar fasciitis when measuring plantar fascia thickness in participants. As well, the side first to be examined was randomly selected in each participant with a flip of a coin. Ultrasound measurements were performed three times at each MTP joint position. Measuring plantar fascia thickness has been found to be more reliable when the mean of three ultrasound measurements was used rather than a single measurement.[5,11,27]

Data Analysis

Data was analyzed using SPSS Statistics Software version 24.0 (IBM Corp, Armonk, NY). Mean $\pm$ standard deviation (SD) was computed for quantitative variables and frequencies (%) for categorical variables. Normality of continuous variables was assessed using Shapiro-Wilk test and box plots. A 2x3 repeated factorial analysis of variance (ANOVA) was conducted to examine the effect of side (involved vs. uninvolved) and MTP joint extension position (at rest vs. 30º vs. max) on plantar fascia thickness (mm) in the plantar fasciitis and control groups. To compare changes in plantar fascia thickness by MTP joint extension position in the uninvolved side between the plantar fasciitis group and control group, 2x3 mixed factorial ANOVA was used. The level of significance was set at $p \leq 0.05$.

Results

The study involved 40 healthy participants (20 with unilateral plantar fasciitis and 20 control) between the ages of 18 and 65 years, all of whom had a body mass index (BMI) below 35 kg/m^2. The mean ± SD age of the participants was 44.8±12.2 years and BMI 26.8±4.5 kg/m^2. The majority were also females (n=26, 65%, see Table 1). In the plantar fasciitis group when analyzing the uninvolved and involved sides by MTP joint extension position, the results from the 2x3 repeated ANOVA showed that there was a significant difference in mean ± SD plantar fascia thickness (mm) among the different positions, at rest vs 30º vs max, (4.6±0.13 vs. 4.3±0.13 vs. 4.2±0.13, $F_{2,38} = 62.2$, $\eta^2=0.77$, $p<0.001$), as well as between involved and uninvolved side (see Table 2.) However, there was no significant interaction between side and position ($F_{2,38} = 0.90$, $p=0.41$). Bonferroni post hoc comparisons showed that mean plantar fascia thickness differed significantly between at rest and 30º, at rest and max, and 30º and max ($p<0.001$).

Table 1. Mean (SD) of general characteristics by group at baseline**.**

	Plantar Fasciitis Group (n = 20)	Control Group (n = 20)
Female, n (%)	13 (65%)	13 (65%)
Age	47 (11.9)	43 (12.6)
BMI	28.3 (4.3)	25.3 (4.3)

Abbreviations: SD, standard deviation; BMI, body mass index.
Units: Age, years; BMI, kg/m^2

In the control group when comparing both sides by MTP joint position, there was a significant difference in mean ± SD plantar fascia thickness among the three different

positions (3.4±0.01 vs. 3.2±0.01 vs. 3.0±0.01, $F_{2,38} = 56.1$, $\eta^2=0.75$, $p<0.001$; see Table 2) and Bonferroni post hoc comparisons showed that mean plantar fascia thickness differed significantly between at rest and 30º, at rest and max, and 30º and max ($p<0.001$). However, there was no significant difference in mean ± SD plantar fascia thickness between right and left side (3.2±0.04 vs. 3.2±0.03, $F_{1,19} = 0.01$, $p=0.92$), and no significant interaction between position and side ($F_{2,38} = 0.24$, $p=0.79$).

Table 2. Mean (SD) plantar fascia thickness (mm) at each MTP joint position by group type.

	Plantar Fasciitis Group (n=20)				Control Group (n=20)			
MTP Joint Extension Position	Involved	Uninvolved	Difference (95% CI)	*p*-value[a] (η^2)	Right	Left	Difference (95% CI)	*p*-value[b] (η^2)
At rest	5.2 (1.1)	3.9 (0.7)	1.3 (0.8-1.8)		3.4 (0.5)	3.4 (0.4)	<0.1 (0.1-0.2)	
30°	4.9 (1.0)	3.7 (0.6)	1.2 (0.8-1.7)	<0.001 (0.60)	3.2 (0.4)	3.2 (0.4)	<0.1 (0.08-0.1)	0.92 (0.00)
Max	4.8 (1.0)	3.6 (0.7)	1.2 (0.7-1.8)		3.0 (0.4)	3.0 (0.4)	<0.1 (0.1-0.2)	
p-value[c] (η^2)	<0.001 (0.77)				<0.001 (0.75)			

Abbreviations: SD, standard deviation; MTP, metatarsophalangeal; CI, confidence interval; η^2, effect
[a] Involved vs uninvolved; [b] Right vs left; [c] MTP joint extension position.

When comparing the uninvolved side from the plantar fasciitis group with the average of two sides from the control group, a significant difference was found in mean ± SD plantar fascia thickness between the two study groups (3.7±0.04 vs. 3.2±0.04, $F_{1,38} = 9.85$, $\eta^2=0.21$, $p=0.003$). A significant difference in mean ± SD plantar fascia thickness among the three different positions (3.7±0.06 vs. 3.5±0.06 vs. 3.3±0.06, $F_{2,76} = 60.4$,

η^2=0.61, p<0.001) was also found with post hoc comparisons showing mean plantar fascia thickness differed significantly between at rest and 30º, at rest and max, and 30º and max (p<0.001). However, there was no significant interaction between position and group ($F_{2,76}$= 0.69, p=0.50).

Discussion

In 1993, the first report of ultrasound being used to measure plantar fascia thickness was published.[34] Since then, ultrasound has become an important tool for not only visualizing the plantar fascia, but is also used to assess the effectiveness of various treatments for plantar fasciitis.[20,23,24] However, the lack of standardization for measuring plantar fascia thickness with ultrasound may make the process more challenging by affecting the accuracy of results. The main concept to ascertain from this study is that as MTP joints are actively extended, the plantar fascia decreases in thickness when observed during ultrasound. The current practice for measuring plantar fascia thickness via ultrasound does not involve a standardized position for the toes. Thus, the MTP joint position can vary depending on the preference of the examiner causing the thickness measurements to potentially vary as well. Ultimately, there is some evidence to suggest a need to re-examine how plantar fascia thickness is measured. Based upon the results from this study, the MTP joint position should be standardized during the ultrasound procedure, either at rest or at max extension to ensure ease of reproducibility. While keeping the toes at rest is most likely the easiest position to replicate and should be the established position when measuring plantar fascia thickness, some clinicians prefer to extend the toes in order to improve the border definition via ultrasound.[5,6,14,27,33] Since the

methodology lacks standardization, it is the recommended that the toes be at rest during the ultrasound measurement for best reproducibility and only at max MTP joint extension when improved visibility of the plantar fascia border is necessary. The position of the MTP joints during the procedure should always be recorded to guarantee consistent protocols are followed in subsequent ultrasound measurements. For example, researchers studying the efficacy of a particular treatment intervention for plantar fasciitis would want to ensure that any change in plantar fascia thickness is due to the intervention and not because of inconsistent toe positioning during the ultrasound procedure.

The average plantar fascia thickness in healthy participants that has been reported in the literature is between 2.6 and 3.9 mm.[3,13,15,26,27,30,34,35] This relatively large range in normative values is most likely due to the discrepancies within the current methodology and participant variation.[27] For instance, Bisi-Balogun et al[5] measured the thickness along different locations of the plantar fascia and found that the mean and ± SD could vary between 2.26 ± 0.4 mm to 3.06 ± 0.6 mm. This is important because the location along the plantar fascia where its thickness is measured has always lacked consistency in the literature.[5,14,15,17] Further complicating the matter is that different segments of the plantar fascia are susceptible to further thickness variations due to gender and body weight characteristics.[14] This has even prompted some authors to suggest comparing the thickness of symptomatic plantar fasciae with contralateral asymptomatic feet in those with unilateral plantar fasciitis rather than compare to a standardized threshold of 4 mm.[17] McMillan et al[23] conducted a systematic review and meta-analysis and found that participants with chronic plantar fasciitis had a plantar fascia thickness that was about 2.2 mm more than the corresponding control participants. In our study, the plantar fascia

thickness of the involved side in the plantar fascia group was significantly higher when compared to the uninvolved side with a difference of 1.2 to 1.3 mm depending on the MTP joint position. One possible reason for the slightly lower difference in contrast to the McMillan et al study could be because the MTP joint extension position was carefully controlled in our study and not in the other studies analyzed in the McMillan et al meta-analysis.

When analyzing the plantar fascia thickness of those in the control group, the two sides were not significantly different (Table 2). But when plantar fascia thickness of the control group was compared to the uninvolved side in the plantar fasciitis group, the uninvolved plantar fascia was still significantly thicker (see Table 2). The literature has been inconclusive on the difference between asymptomatic plantar fasciae in those with unilateral plantar fasciitis and healthy individuals. Some studies have reported that the asymptomatic plantar fasciae in those with unilateral plantar fasciitis were thicker,[33,37] whereas other studies have reported no significant difference between the two groups.[3,34] In this study, the asymptomatic plantar fasciae were thicker than the controls at every MTP joint extension position (Figure 3). The former may be an indication of either an unhealthy compensatory response during gait or an inherent biomechanical flaw that predisposed these individuals with unilateral plantar fasciitis to have increased plantar fascia thickness on the asymptomatic side. Bilateral plantar fasciitis has been reported to be present in 13% to 30% of the cases so it is reasonable to see a slightly thicker asymptomatic plantar fascia in those with unilateral plantar fasciitis as a potential harbinger.[18,19]

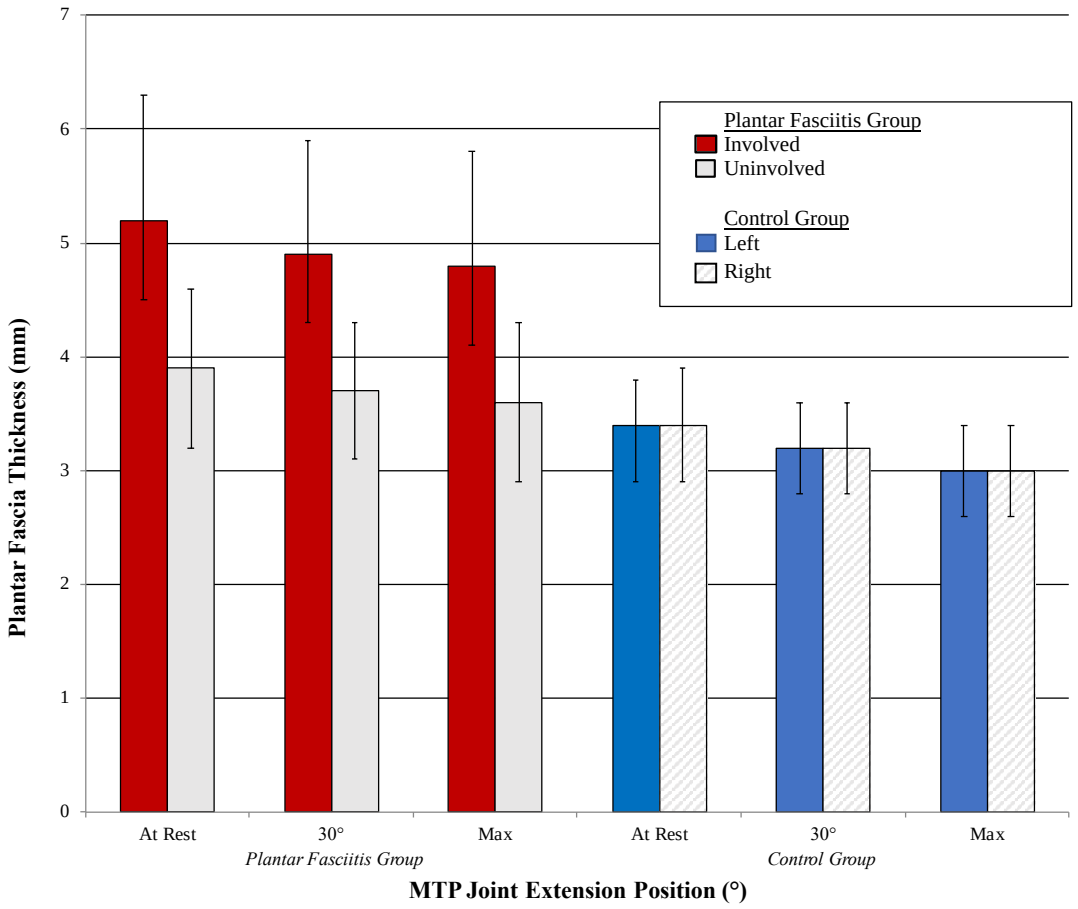

Figure 3. Mean ± SD of plantar fascia thickness (mm) by MTP joint extension position, side, and group. Abbreviations: SD, standard deviation; MTP, metatarsophalangeal.

A limitation of this study was that the examiner was not blind to the position of the MTP joints during the ultrasound procedure. Controlling for this potential bias would be a welcome addition in future studies. As well, it would be of strong interest to assess how MTP joint extension would affect plantar fascia thickness on MRI. Observing a similar relationship on MRI to the ultrasound results in this study would further highlight the need for MTP joint position to be standardized during the ultrasound procedure.

Conclusions

Based upon the findings from this study, the amount of MTP joint extension can strongly influence the ultrasound measurement of plantar fascia thickness and should be taken into account during the procedure. It is recommended that plantar fascia thickness measurements be performed with the toes at rest. If MTP joints must be extended, then the toes should be extended maximally and then noted to ensure subsequent ultrasound procedures are repeated. Standardizing the position of the MTP joints is not only important for attaining the most accurate thickness measurement of the plantar fascia, but is also imperative to researchers who use plantar fascia thickness to determine the effectiveness of various plantar fasciitis interventions.

References

1. Abdel-Wahab N, Fathi S, Al-Emadi S, Mahdi S. High-resolution ultrasonographic diagnosis of plantar fasciitis: a correlation of ultrasound and magnetic resonance imaging. Int J Rheum Dis. 2008;11:279-286.

2. Abul K, Ozer D, Sakizlioglu SS, Buyuk AF, Kaygusuz MA. Detection of normal plantar fascia thickness in adults via the ultrasonographic method. J Am Podiatr Med Assoc. 2015;105(1):8-13. doi:10.7547/8750-7315-105.1.8.

3. Akfirat M, Sen C, Günes T. Ultrasonographic appearance of the plantar fasciitis. Clin Imaging. 2003;27(5):353-357. doi:10.1016/S0899-7071(02)00591-0.

4. Allen RH, Gross MT. Toe flexors strength and passive extension range of motion of the first metatarsophalangeal joint in individuals with plantar fasciitis. J Orthop Sports Phys Ther. 2003;33(8):468-478.

5. Bisi-Balogun A, Cassel M, Mayer F. Reliability of various measurement stations for determining plantar fascia thickness and echogenicity. Diagnostics. 2016;6(2):15. doi:10.3390/diagnostics6020015.

6. Cardinal E, Chhem RK, Beauregard CG, Aubin B, Pelletier M. Plantar fasciitis: sonographic evaluation. Radiology. 1996;201(1):257-259. doi:10.1148/radiology.201.1.8816554.

7. Carlson RE, Fleming LL, Hutton WC. The biomechanical relationship between the tendoachilles, plantar fascia and metatarsophalangeal joint dorsiflexion angle. Foot Ankle Int. 2000;21(1):18-25. doi:10.1177/107110070002100104.

8. Cheng HYK, Lin CL, Chou SW, Wang HW. Nonlinear finite element analysis of the plantar fascia due to the windlass mechanism. Foot Ankle Int. 2008;29(8):845-851. doi:10.3113/FAI.2008.0845.

9. Cheng HYK, Lin CL, Wang HW, Chou SW. Finite element analysis of plantar fascia under stretch-The relative contribution of windlass mechanism and Achilles tendon force. J Biomech. 2008;41(9):1937-1944. doi:10.1016/j.jbiomech.2008.03.028.

10. Cornwall M, McPoil T. Plantar fasciitis: Etiology and treatment. Orthop Sport Phys Ther. 1999;29(12):756-760. doi:10.2519/jospt.1999.29.12.756.

11. Crofts G, Angin S, Mickle KJ, Hill S, Nester CJ. Reliability of ultrasound for measurement of selected foot structures. Gait Posture. 2014;39(1):35-39. doi:10.1016/j.gaitpost.2013.05.022.

12. Garcia CA, Hoffman SL, Hastings MK, Klaesner JW, Mueller MJ. Effect of metatarsal phalangeal joint extension on plantar soft tissue stiffness and thickness. Foot. 2008;18(2):61-67. doi:10.1016/j.foot.2007.12.002.

13. Genc H, Saracoglu M, Nacir B, Erdem HR, Kacar M. Long-term ultrasonographic follow-up of plantar fasciitis patients treated with steroid injection. Jt Bone Spine. 2005;72(1):61-65. doi:10.1016/j.jbspin.2004.03.006.

14. Huerta JP, Garcia JMA. Effect of gender, age and anthropometric variables on plantar fascia thickness at different locations in asymptomatic subjects. Eur J Radiol. 2007;62(3):449-453. doi:10.1016/j.ejrad.2007.01.002.

15. Huerta JP, García JMA, Matamoros EC, Matamoros JC, Martínez TD. Relationship of body mass index, ankle dorsiflexion, and foot pronation on plantar fascia thickness in healthy, asymptomatic subjects. J Am Podiatr Med Assoc. 2008;98(5):379-385. doi:10.7547/0980379.

16. Kappel-Bargas A, Woolf RD, Cornwall MW, McPoil TG. The windlass mechanism during normal walking and passive first metatarsalphalangeal joint extension. Clin Biomech. 1998;13(3):190-194. doi:10.1016/S0268-0033(97)00038-7.

17. Karabay N, Toros T, Hurel C. Ultrasonographic evaluation in plantar fasciitis. J Foot Ankle Surg. 2007;46(6):442-446. doi:10.1053/j.jfas.2007.08.006.

18. Klein SE, Dale AM, Hayes MH, Johnson JE, McCormick JJ, Racette BA. Clinical presentation and self-reported patterns of pain and function in patients with plantar heel pain. Foot Ankle Int. 2012;33(9):693-698. doi:10.3113/FAI.2012.0693.

19. Lapidus P, Guidotti F. Painful heel: Report of 323 patients with 364 painful heels. Clin Orthop Relat Res. 1965;39:178-186.

20. Lee SY, Park HJ, Kwag HJ, et al. Ultrasound elastography in the early diagnosis of plantar fasciitis. Clin Imaging. 2014;38(5):715-718. doi:10.1016/j.clinimag.2012.12.004.

21. Mann RA, Hagy JL. The function of the toes in walking, jogging and running. Clin Orthop Relat Res. 1979;(142):24-29. doi:10.1589/rika.18.41.

22. Martinoli C. Musculoskeletal ultrasound: technical guidelines. Insights Imaging. 2010;1(3):99-141. doi:10.1007/s13244-010-0032-9.

23. McMillan AM, Landorf KB, Barrett JT, Menz HB, Bird AR. Diagnostic imaging for chronic plantar heel pain: a systematic review and meta-analysis. J Foot Ankle Res. 2009;2:32. doi:10.1186/1757-1146-2-32.

24. Mohseni-Bandpei MA, Nakhaee M, Mousavi ME, Shakourirad A, Safari MR, Vahab Kashani R. Application of ultrasound in the assessment of plantar fascia in patients with plantar fasciitis: A systematic review. Ultrasound Med Biol. 2014;40(8):1737-1754. doi:10.1016/j.ultrasmedbio.2014.03.001.

25. Norkin CC, White DJ. Measurement of Joint Motion: A Guide to Goniometry. 5th ed. Philadelphia, PA: F. A. Davis Company; 2016.

26. Ozdemir H, Yilmaz E, Murat A, Karakurt L, Poyraz AK, Ogur E. Sonographic evaluation of plantar fasciitis and relation to body mass index. Eur J Radiol. 2005;54(3):443-447. doi:10.1016/j.ejrad.2004.09.004.

27. Rathleff MS, Moelgaard C, Olesen JL. Intra- and interobserver reliability of quantitative ultrasound measurement of the plantar fascia. J Clin Ultrasound. 2011;39(3):128-134. doi:10.1002/jcu.20787.

28. Riddle DL, Pulisic M, Pidcoe P, Johnson RE. Risk factors for plantar fasciitis: A matched case-control study. J Bone Jt Surg. 2003;85(5):872-877.

29. Riddle DL, Schappert SM. Volume of ambulatory care visits and patterns of care for patients diagnosed with plantar fasciitis: A national study of medical doctors. Foot Ankle Int. 2004;25(5):303-310.

30. Sabir N, Demirlenk S, Yagci B, Karabulut N, Cubukcu S. Clinical utility of sonography in diagnosing plantar fasciitis. J Ultrasound Med. 2005;24(8):1041-1048. doi:24/8/1041 [pii].

31. Stecco C, Corradin M, Macchi V, et al. Plantar fascia anatomy and its relationship with Achilles tendon and paratenon. J Anat. 2013;223(6):665-676. doi:10.1111/joa.12111.

32. Tong KB, Furia J. Economic burden of plantar fasciitis treatment in the United States. Am J Orthop. 2010;39(5):227-231.

33. Tsai WC, Chiu MF, Wang CL, Tang FT, Wong MK. Ultrasound evaluation of plantar fasciitis. Scand J Rheumatol. 2000;29(4):255-259. doi:10.1080/030097400750041415.

34. Wall JR, Harkness MA, Crawford A. Ultrasound diagnosis of plantar fasciitis. Foot Ankle Int. 1993;14(8):465-470. doi:10.1177/107110079301400807.

35. Wearing SC, Smeathers JE, Sullivan PM, Yates B, Urry SR, Dubois P. Plantar fasciitis: Are pain and fascial thickness associated with arch shape and loading? Phys Ther. 2007;87(8):1002-1008. doi:10.2522/ptj.20060136.

36. Wearing SC, Smeathers JE, Urry SR, Hennig EM, Hills AP. The pathomechanics of plantar fasciitis. Sport Med. 2006;36(7):585-611. doi:10.2165/00007256-200636070-00004.

37. Wearing SC, Smeathers JE, Yates B, Sullivan PM, Urry SR, Dubois P. Sagittal movement of the medial longitudinal arch is unchanged in plantar fasciitis. Med Sci Sports Exerc. 2004;36(10):1761-1767. doi:10.1249/01.MSS.0000142297.10881.11.

CHAPTER THREE

EFFECT OF GENDER, JOINT POSITION AND PLANTAR FASCIITIS ON PLANTAR FASCIA THICKNESS

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Abstract

Ultrasound is a widely used diagnostic tool for patients with plantar fasciitis. However, the lack of standardization during the ultrasound measurement for plantar fascia thickness has made it more challenging to understand the etiology of plantar fasciitis, as well as identify risk factors, such as gender. One critical component lacking any standardization during the procedure is metatarsophalangeal (MTP) joint position as ultrasound examiners often extend the toe position during the process. The purpose of this study was to investigate gender differences regarding plantar fascia thickness while controlling for MTP joint position in healthy and those with unilateral plantar fasciitis. The plantar fascia thickness of forty participants (20 with unilateral plantar fasciitis and 20 control) was measured via ultrasound three times at three different MTP joint positions: 1) at rest, 2) 30 degrees of extension from the plantar surface, and 3) maximal extension possible. When comparing gender differences, males in the plantar fasciitis group had a significantly thicker plantar fascia when compared to female counterparts ($P=0.048$). However, no significant differences were observed between healthy males and females. The males with unilateral plantar fasciitis also had significantly thicker asymptomatic plantar fasciae collectively compared to controls ($P<0.05$), whereas females with unilateral plantar fasciitis had a similar but not significant change. It appears that healthy males and females first begin with very similar plantar fascia thickness levels. However, as the onset of plantar fasciitis develops, males tend to develop thicker plantar fasciae than their female counterparts.

Introduction

Plantar fasciitis has been reported to be the most common cause of heel pain,[9,21,34,44] accounting for up to 80% of all cases of plantar heel pain.[41] From 1995 to 2000, approximately one million outpatient visits for plantar fasciitis were made annually.[40] In 2007, treatment costs for patients with plantar fasciitis in the United States was estimated to be between $192-376 million dollars.[48] Often described as an inflammatory condition, plantar fasciitis should more appropriately be considered a degenerative condition of the plantar fascia, exhibiting pain most commonly at the medial tubercle of the calcaneus. Although the condition is very common, little is known about its etiology.[39,51] The current theory is that plantar fasciitis develops from excessive tensile forces imposed onto the plantar fascia and is aggravated from prolonged weight bearing or walking.[39]

Studies regarding gender and plantar fasciitis have been inconsistent. Some studies have indicated that men are more likely to develop plantar fasciitis,[23,47] whereas other studies have reported plantar fasciitis being more common in women.[11,13,18,36,43] For instance, Taunton et al[47] found in their study on runners that males were more likely to develop plantar fasciitis than females (54% vs 46% respectively). In contrast, Scher et al[43] found that the incidence rate for plantar fasciitis amongst women in the United States military was nearly double that of their male counterparts.

While no gold standard exists for diagnosing plantar fasciitis, the condition is often diagnosed with a thorough clinical history and physical examination.[21,39,41,50] Nevertheless, the use of diagnostic imaging has become an indispensable tool for clinicians and researchers to investigate and confirm plantar fasciitis.[30,31] Although plain

radiographs and magnetic resonance imaging (MRI) have their roles, ultrasound has emerged as a low cost, noninvasive, radiation-free option for examining the plantar fascia with accuracy levels comparable to MRI.[1,42] In fact, ultrasound has been identified as the fastest developing technique in musculoskeletal imaging.[29]

According to several studies using ultrasound, a plantar fascia thickness over 4 mm was found to be consistent with plantar fasciitis.[2,3,30,49,50] However, similar to the inconsistent study findings regarding the prevalence of plantar fasciitis amongst men and women, the plantar fascia thickness norms for men and women have also varied in the literature. Some studies have found no differences in plantar fascia thickness between men and women,[14,20,34,50] whereas other studies have identified men as having a higher plantar fascia thickness level when compared to women.[2,20,45] A study by Huerta and Garcia[20] found the difference in plantar fascia thickness between men and women varied depending on where it was measured on the plantar fascia.

Gender and its inconsistent relationship in the literature pertaining to the plantar fascia are still unclear. In regard to plantar fascia thickness, a possible reason for the inconsistency could be the lack of standardization of the ultrasound measurement process leading to a large variation in recorded values amongst the studies. For example, the European Society of Musculoskeletal Radiology published its procedural recommendations for how the plantar fascia thickness should be measured,[29] but a recommendation for how the toes should be positioned during the examination was absent. While authors in some studies leave the toes in a neutral resting position, others have advocated that the toes be extended to improve the border definition of the plantar fascia during the ultrasound procedure and make the measurement process easier.[8,9,20,37,49]

A pervious study from our research group demonstrated that extending the toes during the procedure resulted in a significant decrease in the plantar fascia thickness and in effect altered the acquired ultrasound measurements.[17] If the metatarsophalangeal (MTP) joint position was standardized during the ultrasound measurement for plantar fascia thickness, possibly a clear relationship between plantar fascia thickness and gender would be uncovered. Ultimately, this could be a positive first step into understanding how plantar fasciitis differs between men and women and possibly provide insight on how to better treat patients diagnosed with plantar fasciitis.

The objectives of this cross-sectional study were: 1) examine the changes in plantar fascia thickness by gender, MTP joint extension position, and side in the plantar fasciitis group, 2) examine gender differences in plantar fascia thickness in each MTP joint extension position in each side in both groups; and 3) compare plantar fascia thickness in each MTP joint extension position between the uninvolved side in the plantar fasciitis group and control in males and females separately.

Materials and Methods

Participants

All participants signed an informed consent, and the study was approved by the Institutional Review Board of Loma Linda University. Participants with plantar fasciitis were required to exhibit the classic symptoms of plantar fasciitis (i.e., plantar heel tenderness, morning pain with the first few steps out of bed) and have had symptoms persisting longer than 6 weeks to ensure participants were not in an acute phase of the condition. Individuals were excluded from the study if they had any neurologic, systemic

inflammatory, metabolic, connective tissue, or inner-ear disorders. Those with severe toe deformities, trauma/surgery to the lumbar spine or lower extremities, an antalgic gait pattern, a cortisone injection over the preceding three months, or recent consumption of balance-altering medication were also excluded from the study.

Measurement of Plantar Fascia Thickness

Sagittal thickness of the plantar fascia was measured with a 13-6 MHz linear array transducer (Sonosite M-Turbo Ultrasound System, Bothell, WA, USA) and acoustic coupling gel applied onto the plantar surface of the heel. Participants were positioned in prone with the examined foot over the edge of the examination table and the ankle in neutral. The transducer was positioned over the plantar surface of the heel approximately 0.5 cm medial to the midline longitudinal axis of the foot in order to visualize a longitudinal view of the plantar fascia. The thickness of the plantar fascia was then measured at the anterior margin of the calcaneus.

The ultrasound measurement was performed with the toes in three different MTP joint positions: 1) at rest, 2) 30 degrees of active extension from the plantar surface, and 3) maximal extension actively possible by the participant. All of the toes were extended passively together to the desired position by the examiner whereby the participant was then asked to actively hold the position while the examiner continued to monitor for any movement. Goniometry was only performed when the MTP joints were extended to 30 degrees as measurement was not necessary in the at rest or max extension positions. Measurement of first MTP joint extension was performed on the medial aspect of the foot with the proximal arm of the goniometer parallel with the plantar surface of the foot and

the distal arm aligned with the midline of the proximal phalanx of the first toe. The traditional method for measuring extension at the first MTP joint involves aligning the proximal arm of the goniometer with first metatarsal, either dorsally or over the medial surface of the foot rather than the plantar surface of the foot.[33] A modification was employed in an effort to make comparisons between feet from different individuals more reliable as outlined by Allen and Gross.[4] In the foot-flat position, the MTP joints are typically extended 20 degrees from the midline of the metatarsals.[27] However, it was felt that different foot types could result in the first metatarsal having a variable position. The plantar surface of the foot being fixed would not suffer from this inconsistency and would allow for a "standard" position in between the two other MTP joint positions (i.e., at rest and at max extension). When at rest and at max extension, a specific joint angle was not necessary, which was why goniometry was not performed. Ultrasound measurements conducted with the MTP joints at rest were intended to place the least amount of tension onto the plantar fascia, whereas maximal MTP joint extension was necessary to apply the most amount of tension. A standard MTP joint position during the initial and final conditions of ultrasound measurements would had most likely resulted in relative inaccurate tissue tension in some participants (i.e., presence of unwanted plantar fascia tension at the initial position or inadequate plantar fascia tension when the MTP joints were extended maximally).

The ultrasound examinations were performed by a single licensed physical therapist with sixteen years of clinical experience, who had completed several continuing education radiology courses. As well, prior to the study the examiner met with a certified ultrasound technician for four instructional sessions over the course of one month to

become familiar with the equipment and technique. During the study, the examiner was blind to which foot was afflicted with plantar fasciitis when measuring plantar fascia thickness in participants. As well, the side first to be examined was randomly selected in each participant with a flip of a coin. Ultrasound measurements were performed three times at each MTP joint position. Measuring plantar fascia thickness has been found to be more reliable when the mean of three ultrasound measurements was used rather than a single measurement.[8,10,37]

Data Analysis

Data was analyzed using SPSS Statistics Software version 24.0 (IBM Corp, Armonk, NY). Mean ± SD was computed for quantitative variables and counts (%) for categorical variables. Normality of quantitative variables was assessed using Shapiro-Wilk test and box plots. We compared mean age (years), and Body Mass Index (kg/m^2) between the two groups using independent t-test. The distribution of gender by group type was examined using Fisher's Chi Square test. A 2x2x3 mixed factorial analysis of variance (ANOVA) was conducted to examine the effect of gender, MTP joint extension position (at rest vs. 30 degrees vs. maximum), and side on plantar fascia thickness (mm) in each study group. Because there was a significant interaction between position and gender, and side and gender, we compared changes in plantar fascia thickness in each position and side between males and females using independent-test. Also, independent t-test was used to compare plantar fascia thickness in each MTP joint extension position between the uninvolved side in the plantar fasciitis group and control in males and females separately. The level of significance was set at $p < 0.05$.

Results

A sample of 40 participants (20 with plantar fasciitis and 20 control) with mean age 44.8±12.2 years and BMI 26.8±4.5 kg/m^2 participated in this study. The majority were females (n=26, 65%) and right dominant (n=38, 95%). There was no significant difference between males and females in mean age and BMI ($p>0.05$, Table 1).

Table 1. Participant characteristics by gender and group

	Plantar Fasciitis Group			Control Group		
	Male (n =7)	Female (n = 13)	P-value	Male (n =7)	Female (n = 13)	P-value
Age	43.0 (12.6)	48.5 (11.5)	0.33	31.9 (9.6)	48.9 (9.8)	0.002
BMI	27.0 (4.6)	28.9 (4.2)	0.35	26.4 (2.5)	24.8 (5.0)	0.42
Involved Side (R/L)	4/3	6/7		N/A	N/A	

Abbreviations: SD, standard deviation; BMI, body mass index; R/L, right/left

Units: Age, years; BMI, (kg/m^2)

In the plantar fasciitis group, there was a significant interaction between side and gender ($F_{1,18}$= 5.7, p=0.01) and position and gender ($F_{2,36}$ = 4.5, p=0.02), and the changes in thickness differed by position ($F_{2,36}$ = 9.1, p=0.001) and between males and females (0.47±0.03 versus 0.41±0.02; F_1, 18= 3.1, p=0.048). However, in the control group (Table 2), there was a significant difference in mean thickness by position ($F_{2,36}$ = 44.0, $p<0.001$), but not by side (0.33±0.01 versus 0.31±0.01; $F_{1,18}$ = 2.1, p=0.32) and between males and females (0.32±0.02 versus 0.32±0.01; $F_{1,18}$ = 0.01, p=0.92).

Table 2. Mean (SD) plantar fascia thickness (mm) in healthy males versus females

	Control Group (n =20, males = 7)							
	Right				Left			
MTP joint extension position	Male	Female	Difference (CI)	P-value* (η^2)	Male	Female	Difference (CI)	P-value* (η^2)
At rest	3.4 (0.4)	3.4 (0.5)	0.0 (-0.5, 0.5)	0.96 (0.00)	3.4 (0.3)	3.5 (0.4)	-0.1 (-0.4, 0.3)	0.78 (0.28)
30 degrees	3.2 (0.5)	3.2 (0.4)	0.0 (-0.4, 0.5)	0.94 (0.00)	3.1 (0.1)	3.2 (0.4)	-0.1 (-0.4, 0.3)	0.63 (0.34)
Max	2.9 (0.5)	3.0 (0.5)	-0.1 (-0.6, 0.4)	0.78 (0.02)	3.0 (0.5)	3.0 (0.4)	0.0 (-0.3, 0.5)	0.74 (0.00)

Abbreviations: SD, standard deviation; MTP, metatarsophalangeal; CI, confidence interval; η^2, effect size

* Independent t-test

In the plantar fasciitis group, differences in mean thickness by gender and position in the involved and uninvolved side are displayed in Table 3. Males tended to have a thicker thickness than females (Cohen's effect sizes ranged from 0.5 to 0.9), however, not statistically significant. In the control group, differences in mean thickness by gender and position in the right and left side are displayed in Table 2. There was no significant difference in mean thickness between males and females (P>0.05).

Table 3. Mean (SD) plantar fascia thickness (mm) in males versus females with unilateral plantar fasciitis

	Plantar Fasciitis Group (n =20, males = 7)							
	Involved				Uninvolved			
MTP joint extension position	Male	Female	Difference (CI)	P-value* (η^2)	Male	Female	Difference (CI)	P-value* (η^2)
At rest	5.7 (0.9)	5.0 (1.2)	0.7 (-0.4, 1.8)	0.18 (0.65)	4.2 (0.7)	3.8 (0.6)	0.4 (-0.3, 1.1)	0.22 (0.61)
30 degrees	5.2 (0.7)	4.8 (1.1)	0.4 (-0.6, 1.4)	0.38 (0.43)	4.0 (0.6)	3.6 (0.6)	0.4 (-0.1, 1.1)	0.13 (0.67)
Max	5.1 (0.6)	4.6 (1.1)	0.5 (-0.5, 1.5)	0.22 (0.56)	4.0 (0.8)	3.3 (0.6)	0.7 (-0.1, 1.3)	0.07 (0.93)

Abbreviations: SD, standard deviation; MTP, metatarsophalangeal; CI, confidence interval; η^2, effect size

* Independent t-test

The difference in mean thickness between the uninvolved side in the plantar fasciitis group and the control group is displayed in Table 4. In males, there was a significant difference between the uninvolved side in the plantar fasciitis group and the control ($P<0.05$, Cohen's effect sizes ranged from 1.5 to 2.1), but not in females ($P>0.05$, Cohen's effect sizes ranged from 0.6 to 0.8).

Table 4. Mean (SD) plantar fascia thickness (mm) in uninvolved versus control by gender

	Uninvolved Side of Plantar Fasciitis Group vs Control Group† (n =20, males = 7)							
	Male				Female			
MTP joint extension position	Uninvolved	Control	Difference (CI)	P-value* (η^2)	Uninvolved	Control	Difference (CI)	P-value* (η^2)
At rest	4.2 (0.7)	3.4 (0.3)	0.8 (0.1, 1.4)	0.03 (1.49)	3.8 (0.6)	3.5 (0.4)	0.3 (-0.1, 0.8)	0.13 (0.59)
30 degrees	4.0 (0.6)	3.1 (0.1)	0.9 (0.3, 1.5)	0.01 (2.09)	3.6 (0.6)	3.2 (0.4)	0.3 (-0.1, 0.7)	0.10 (0.78)
Max	4.0 (0.8)	3.0 (0.5)	0.9 (0.2, 1.7)	0.02 (1.50)	3.3 (0.6)	3.0 (0.4)	0.4 (-0.1, 0.8)	0.07 (0.59)

Abbreviations: SD, standard deviation; MTP, metatarsophalangeal; CI, confidence interval; η^2, effect size

† Left leg

* Independent t-test

Discussion

Gamba et al recently questioned the clinical importance of using plantar fascia thickness with treatment planning for plantar fasciitis as they found no relationship between plantar fascia thickness with pain, function, or patient health and quality of life surveys.[15] As well, the relationship of gender with plantar fascia thickness and plantar fasciitis has always been inconsistent in the literature. Plantar fascia thickness has been found to either be thicker in males or have no gender difference.[2,14,20,34,45,50] Evidence can be found to support the implication that plantar fasciitis is more common in either males or females.[11,13,18,23,36,43,47] A possible reason for these inconsistencies in the literature regarding plantar fascia thickness could be due to the lack of standardization of the

ultrasound measurement process, a concept heralded by other researchers.[20,21] For example, the position of the MTP joints during the procedure has varied amongst ultrasound examiners with some leaving the toes at rest and others extending the toes to better visualize the plantar fascia by improving its borders during the sonogram. We have demonstrated that extending the MTP joints effectively caused the plantar fascia to become much thinner.[17] If the MTP joints were not standardized by ultrasound examiners in previous studies, it could explain why concepts pertaining to plantar fascia thickness have varied. In our study, plantar fascia thickness was compared at three different MTP joint extension positions in hopes of controlling for the influence of MTP joint extension. In the control group, mean plantar fascia thickness was found to significantly decrease as MTP joint extension increased ($P<0.001$). A similar finding was also present in the plantar fasciitis group ($P=0.001$). If in the plantar fasciitis group, the plantar fascia thickness in males with MTP joint extended maximally was compared to females with plantar fasciitis with the MTP joints at rest, both thickness levels would present very similarly (i.e., male: 5.1 mm vs female: 5.0 mm) (Table 3). In contrast, if both were compared at the same MTP joint position either at rest or at max extension, a difference ranging between 0.5 to 0.7 mm would be observed between the two genders. While this amount may not seem much, the actual difference can range between 0.4 to 1.8 mm (according to the 95% confidence interval) when comparing involved plantar fasciae between males versus females with the MTP joints at rest. Thus, the position of the MTP joint must be standardized to appropriately compare plantar fascia thickness between males to females.

When comparing the plantar fascia thickness between healthy males and females, no significant difference in plantar fascia thickness was found collectively (P=0.92) or at any MTP joint extension position (Table 2). Previous studies have also found no difference in plantar fascia thickness between males and females,[14,20,34,50] which is in contrast to other studies that identified men as having thicker plantar fasciae when compared to women.[2,20,45] Huerta and Garcia found males had increased plantar fascia thickness when measured 1 cm proximal to the plantar fascia insertion, whereas they found no difference amongst males and females when the thickness was measured at the insertion (i.e., anterior border of the calcaneus where the plantar fascia just leaves the calcaneal tuberosity), 1 cm or 2 cm distal to insertion.[20] In our study, we measured plantar fascia thickness at the insertion, a location consistent with musculoskeletal ultrasound guidelines.[29] While Huerta and Garcia found the plantar fascia thickness to vary by gender depending where along the plantar fascia the thickness was measured, it was indicated in their methodology that they occasionally dorsiflexed the toes during their examination. To what degree the toes were extended, how many participants, and during what locations on the plantar fascia when thickness was measured were all concepts not clarified in their study that could had affected their results.

While no significant difference was found with plantar fascia thickness between healthy males and females in our study, the results notably change when our investigation involved individuals with unilateral plantar fasciitis. When both plantar fasciae (i.e., involved and uninvolved sides) in males were compared to both plantar fasciae in females, men had significantly thicker plantar fascia (P=0.048). While plantar fascia thickness in males and females did not significantly differ when involved plantar fasciae

or uninvolved plantar fasciae were compared individually between the genders, males were still consistently observed to have thicker plantar fasciae at each MTP joint position with medium to large effect sizes (Table 3).

The lack of clarity in the literature regarding plantar fascia thickness has continued when comparing plantar fasciae in healthy individuals with asymptomatic plantar fasciae in those with unilateral plantar fasciitis. Some studies have reported no significant difference between the two groups,[3,50] while other studies have reported the asymptomatic plantar fasciae in those with unilateral plantar fasciitis being thicker.[49,52] In our study, the asymptomatic plantar fasciae were significantly thicker than the controls in males at every MTP joint extension position (P=0.03, P=0.01, P=0.02) with very large effect sizes (Table 4). In females, the uninvolved plantar fasciae tended to be thicker with moderate effect sizes at each MTP joint extension position, though not statistically significant. The presence of increased plantar fascia thickness contralateral to the side afflicted with plantar fasciitis could be an indication of an altered gait pattern often found in those with plantar fasciitis.[35] The importance of studying the asymptomatic plantar fasciae in those with unilateral plantar fasciitis is that bilateral plantar fasciitis has been reported in 13% to 30% of the cases.[22,23] Thus, it may be reasonable to observe a slightly thicker asymptomatic plantar fascia in those with unilateral plantar fasciitis.

It has often been reported anecdotally that women have a higher susceptibility to developing plantar fasciitis.[5,34,44] While the relationship between gender and plantar fasciitis has always been historically unclear, more recent research has suggested that plantar fasciitis is more prevalent in females than males.[13,18,38] Furthermore, the studies reporting males as being more susceptible to plantar fasciitis had some potential flaws. In

the study by Lapides and Guidotti who found men to be more likely to develop plantar fasciitis, their study population may had been biased since the study was published in the 1960s and did not include women from a fully integrated industry and weightbearing work force.[23] Other authors have commented on this flaw, as well.[6,11,12] In another study that found men more likely to develop plantar fasciitis, Taunton et al speculated that another pathological variable may had not been accounted for that influenced their results.[47] While foot pain in general has been reported to be more common in women in large population-based studies,[19,32] the exact reasons, especially regarding plantar fasciitis have yet to be identified. Some have suggested that the architecture and mechanical properties of the plantar fascia in women differing with that of men as a possible cause.[38] Women have also been observed to utilize healthcare services more than men,[7] which could possibly explain higher percentages of women being diagnosed with plantar fasciitis in various medical databases.[13] Nevertheless, the evidence supporting the view that women are more at risk for plantar fasciitis is mounting.[11,13,18,36,43]

If women are more likely to develop plantar fasciitis, it could be hypothesized that they would exhibit a thicker plantar fascia when compared to males. However, no known study to us has corroborated that concept. Furthermore, our study found that healthy males and females to be nearly identical (Table 2). In the plantar fasciitis group, men collectively had a significantly thicker plantar fascia in comparison to females (P=0.048). There were no significant differences between males and females regarding BMI in either cohort group (Table 1), a factor often associated with gender and increased plantar fascia thickness.[34,36,46] Thus, BMI could not had been a confounding variable in our results.

Since a plantar fascia thickness over 4 mm has been found to be consistent with plantar fasciitis,[2,3,30,49,50] the increase in plantar fascia thickness has been viewed as a negative attribute. However, in conjunction with the results from our study, the findings from Gamba et al[15] regarding the lack of relationship between plantar fascia thickness and negative clinical markers (i.e., pain, function, patient surveys) may serve to change how we view of plantar fascia thickness and how it relates to gender. The males with unilateral plantar fasciitis had significantly thicker asymptomatic plantar fasciae collectively compared to controls ($P<0.05$), as well as at each MTP joint extension position ($P=0.03$, $P=0.01$, $P=0.02$) with very large effect sizes (Table 4). If women are more likely to develop plantar fasciitis based upon the growing evidence and if males with unilateral plantar fasciitis develop thicker plantar fasciae than females as found in our study results, could an increase in plantar fascia thickness be viewed as a positive response. In other words, could the increase in plantar fascia thickness actually be a protective mechanism for avoiding pain and other symptoms associated with plantar fasciitis? If the plantar fascia thickening is the body's response to the supposedly excessive tensile stresses, it is reasonable to understand that the increase in thickness has protective properties, which may be why Gamba et al did not observe in their study its correlation with negative clinical markers associated with plantar fasciitis.

Another observation that differed between males and females with plantar fasciitis was the amount of change in plantar fascia thickness between the various MTP joint extension positions (Figure 1). Males with plantar fasciitis tended to exhibit most of the decrease in plantar fascia thickness between the MTP joint positions of at rest and 30 degrees and then very little change from 30 degrees to max extension.

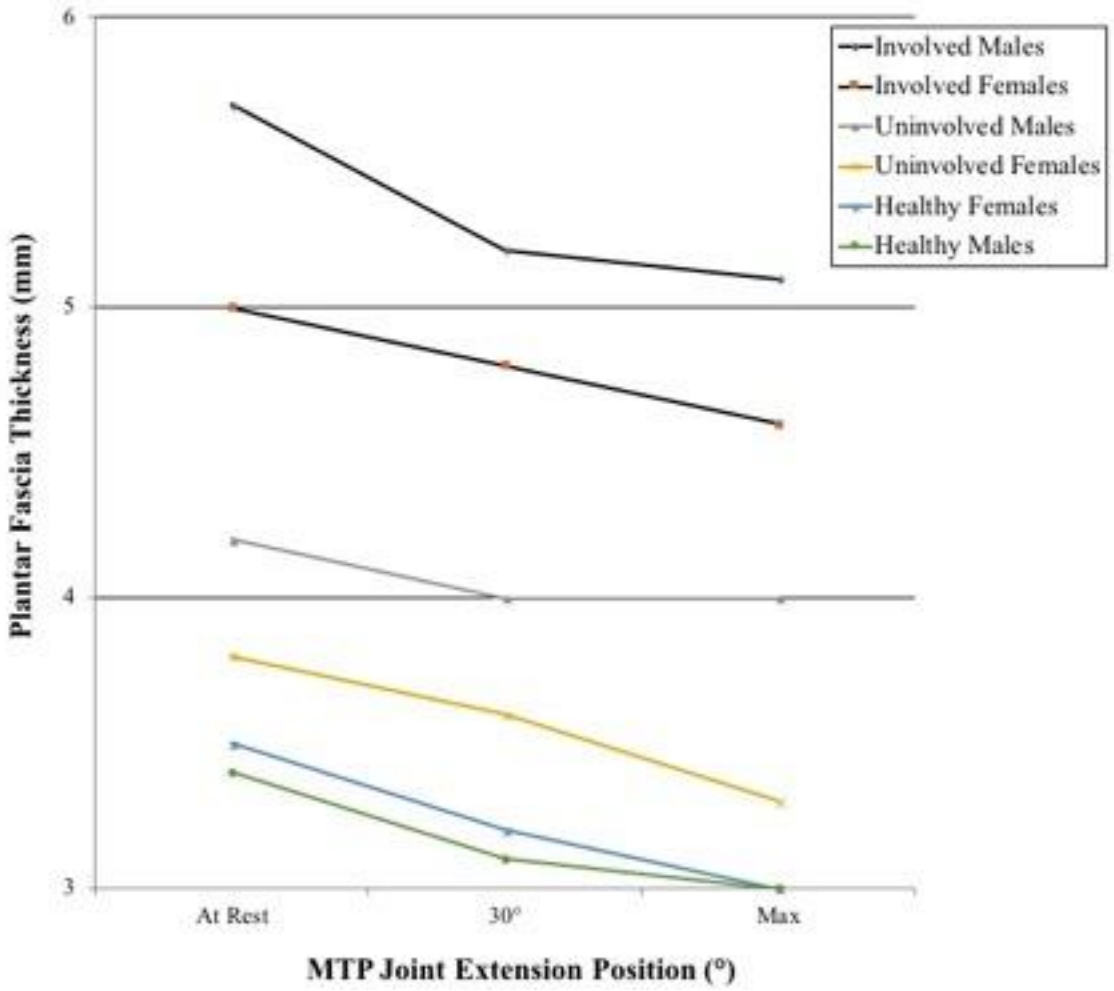

Figure 1. Change in plantar fascia thickness at each MTP joint position by gender in both groups

In contrast, females with plantar fasciitis had a consistent level of change in plantar fascia thickness throughout the various MTP joint extension positions. If the majority of the elongation of the plantar fascia in males occurs between at rest and 30 degrees of MTP joint extension, then it could be hypothesized that the plantar fasciae in males with plantar fasciitis are able to resist elongation and tensile forces better than females. It could also be hypothesized that males reach the elongation limit much earlier

than females because the predominant mechanism for males with plantar fasciitis is due to tissue tightness and/or a lack of flexibility (i.e., gastroc-soleus, tendoachilles). In contrast, the results observed in females were possibly due to having more tissue elasticity pointing to the possibility that the predominant mechanism of plantar fasciitis in women has less to do with tissue tightness and more to do a lack of strength within the kinetic chain (e.g., muscle, tendon, fascia). Ultimately, this may foreshadow how gender could play a role in the treatment planning for those with plantar fasciitis.

The reported recovery time from plantar fasciitis of 6 to 18 months has prompted many to question the efficacy of the current treatment options prescribed to patients.[11,28,53] Further complicating the management of this condition is that the exact etiology is still unknown.[24,26] Based upon our results, it is fair to ask if a contributing factor for the long recovery times is because elements associated with gender had never before been considered or utilized. Future studies could possibly examine different treatment options for plantar fasciitis that consider gender, such as stretching and joint mobilization being emphasized more so with males and taping/splinting, strengthening, and orthotics for females.

This study has some limitations that must be noted. The small sample size, especially with that of males in comparison to females should be acknowledged. There was no blinding of the MTP joint position during the ultrasound examination. However, it is felt that the average of three measurements was used in an effort to provide the most accurate measure of plantar fascia thickness at each MTP joint extension position. The menstrual cycle state of the females was also not recorded, which could had influenced the plantar fascia thickness measurements.

Conclusion

Gender and its relationship pertaining to the plantar fascia thickness and plantar fasciitis have historically been unclear. However, controlling for MTP joint extension position and the growing evidence involving large medical databases and recently published long-term studies are shedding some light. Our separate findings of healthy males and females with similar plantar fascia thickness levels contrasted by males with plantar fasciitis exhibiting thicker plantar fasciae in comparison to females may mirror and explain to some extent the inconsistency found within the literature. This may lay the groundwork for considering gender when developing a treatment plan for individuals with plantar fasciitis.

References

1. Abdel-Wahab N, Fathi S, Al-Emadi S, Mahdi S. High-resolution ultrasonographic diagnosis of plantar fasciitis: a correlation of ultrasound and magnetic resonance imaging. *Int J Rheum Dis*. 2008;11:279-286.

2. Abul K, Ozer D, Sakizlioglu SS, Buyuk AF, Kaygusuz MA. Detection of normal plantar fascia thickness in adults via the ultrasonographic method. *J Am Podiatr Med Assoc*. 2015;105(1):8-13. doi:10.7547/8750-7315-105.1.8.

3. Akfirat M, Sen C, Günes T. Ultrasonographic appearance of the plantar fasciitis. *Clin Imaging*. 2003;27(5):353-357. doi:10.1016/S0899-7071(02)00591-0.

4. Allen RH, Gross MT. Toe flexors strength and passive extension range of motion of the first metatarsophalangeal joint in individuals with plantar fasciitis. *J Orthop Sports Phys Ther*. 2003;33(8):468-478.

5. Barrett S, O'Malley R. Plantar fasciitis and other causes of heel pain. *Am Fam Physician*. 1999;59(8):2200-2206.

6. Bartold SJ. The plantar fascia as a source of pain - Biomechanics, presentation and treatment. *J Bodyw Mov Ther*. 2004;8(3):214-226. doi:10.1016/S1360-8592(03)00087-1.

7. Bertakis KD, Azari R, Callahan EJ, Robbins JA. Gender Differences in the Utilization of Health care Services. *J Fam Pract*. 2000;49(2):147-152.

8. Bisi-Balogun A, Cassel M, Mayer F. Reliability of various measurement stations for determining plantar fascia thickness and echogenicity. *Diagnostics*. 2016;6(2):15. doi:10.3390/diagnostics6020015.

9. Cardinal E, Chhem RK, Beauregard CG, Aubin B, Pelletier M. Plantar fasciitis: sonographic evaluation. *Radiology*. 1996;201(1):257-259. doi:10.1148/radiology.201.1.8816554.

10. Crofts G, Angin S, Mickle KJ, Hill S, Nester CJ. Reliability of ultrasound for measurement of selected foot structures. *Gait Posture*. 2014;39(1):35-39. doi:10.1016/j.gaitpost.2013.05.022.

11. Davis PF, Severud E, Baxter DE. Painful heel syndrome: Results of nonoperative treatment. *Foot Ankle Int*. 1994;15(10):531-535. doi:10.1177/107110079401501002.

12. DeMaio M, Paine R, Mangine RE, Drez D. Plantar Fasciitis. *Orthopedics*. 1993;16(10):1155-1163. doi:10.3928/0147-7447-19931001-13.

13. Fraser JJ, Glaviano NR, Hertel J. Utilization of physical therapy intervention among patients with plantar fasciitis in the United States. *J Orthop Sport Phys Ther*. 2017;47(2):49-55. doi:10.2519/jospt.2017.6999.

14. Gadalla N, Kichouh M, Boulet C, Machiels F, De Mey J, De Maeseneer M. Sonographic evaluation of the plantar fascia in asymptomatic subjects. *Jbr-Btr*. 2014;97(5):271-273.

15. Gamba C, Sala-Pujals A, Perez-Prieto D, et al. Relationship of Plantar Fascia Thickness and Preoperative Pain, Function, and Quality of Life in Recalcitrant Plantar Fasciitis. *Foot Ankle Int*. 2018:107110071877204. doi:10.1177/1071100718772041.

16. Gibbon W. Plantar fasciitis: US imaging (letter). *Radiology*. 1992;182(1):285.

17. Granado MJ, Lohman III EB, Gordon KE, Daher NS. Metatarsophalangeal joint extension changes ultrasound measurements for plantar fascia thickness. *J Foot Ankle Res*. 2018;11:20. doi:10.1186/s13047-018-0267-0.

18. Hansen L, Krogh TP, Ellingsen T, Bolvig L, Fredberg U. Long-term prognosis of plantar fasciitis: A 5- to 15-year follow-up study of 174 patients with ultrasound examination. *Orthop J Sport Med*. 2018;6(3):1-9. doi:10.1177/2325967118757983.

19. Hill CL, Gill TK, Menz HB, Taylor AW. Prevalence and correlates of foot pain in a population-based study: The North West Adelaide health study. *J Foot Ankle Res*. 2008;1(2). doi:10.1186/1757-1146-1-2.

20. Huerta JP, Garcia JMA. Effect of gender, age and anthropometric variables on plantar fascia thickness at different locations in asymptomatic subjects. *Eur J Radiol*. 2007;62(3):449-453. doi:10.1016/j.ejrad.2007.01.002.

21. Karabay N, Toros T, Hurel C. Ultrasonographic evaluation in plantar fasciitis. *J Foot Ankle Surg*. 2007;46(6):442-446. doi:10.1053/j.jfas.2007.08.006.

22. Klein SE, Dale AM, Hayes MH, Johnson JE, McCormick JJ, Racette BA. Clinical presentation and self-reported patterns of pain and function in patients with plantar heel pain. *Foot Ankle Int*. 2012;33(9):693-698. doi:10.3113/FAI.2012.0693.

23. Lapidus P, Guidotti F. Painful heel: Report of 323 patients with 364 painful heels. *Clin Orthop Relat Res*. 1965;39:178-186.

24. League AC. Current concepts review: Plantar fasciitis. *Foot Ankle Int*. 2008;29(3):358-366. doi:10.3113/FAI.2008.0358.

25. Lee SY, Park HJ, Kwag HJ, et al. Ultrasound elastography in the early diagnosis of plantar fasciitis. *Clin Imaging*. 2014;38(5):715-718. doi:10.1016/j.clinimag.2012.12.004.

26. Lemont H, Ammirati KM, Usen N. Plantar fasciitis. *J Am Podiatr Med Assoc*. 2003;93(3):234-237. doi:10.7547/87507315-93-3-234.

27. Mann RA, Hagy JL. The function of the toes in walking, jogging and running. *Clin*

Orthop Relat Res. 1979;(142):24-29. doi:10.1589/rika.18.41.

28. Martin RL, Irrgang JJ, Conti SF. Outcome study of subjects with insertional plantar fasciitis. *Foot Ankle Int*. 1998;19(12):803-811. doi:10.1177/107110079801901203.

29. Martinoli C. Musculoskeletal ultrasound: technical guidelines. *Insights Imaging*. 2010;1(3):99-141. doi:10.1007/s13244-010-0032-9.

30. McMillan AM, Landorf KB, Barrett JT, Menz HB, Bird AR. Diagnostic imaging for chronic plantar heel pain: a systematic review and meta-analysis. *J Foot Ankle Res*. 2009;2:32. doi:10.1186/1757-1146-2-32.

31. Mohseni-Bandpei MA, Nakhaee M, Mousavi ME, Shakourirad A, Safari MR, Vahab Kashani R. Application of ultrasound in the assessment of plantar fascia in patients with plantar fasciitis: A systematic review. *Ultrasound Med Biol*. 2014;40(8):1737-1754. doi:10.1016/j.ultrasmedbio.2014.03.001.

32. Mølgaard C, Lundbye-Christensen S, Simonsen O. High prevalence of foot problems in the Danish population: A survey of causes and associations. *Foot*. 2010;20(1):7-11. doi:10.1016/j.foot.2010.03.002.

33. Norkin CC, White DJ. *Measurement of Joint Motion: A Guide to Goniometry*. 5th ed. Philadelphia, PA: F. A. Davis Company; 2016.

34. Ozdemir H, Yilmaz E, Murat A, Karakurt L, Poyraz AK, Ogur E. Sonographic evaluation of plantar fasciitis and relation to body mass index. *Eur J Radiol*. 2005;54(3):443-447. doi:10.1016/j.ejrad.2004.09.004.

35. Phillips A, McClinton S. Gait deviations associated with plantar heel pain: A systematic review. *Clin Biomech*. 2017;42:55-64. doi:10.1016/j.clinbiomech.2016.12.012.

36. Rano JA, Fallat LM, Savoy-Moore RT. Correlation of heel pain with body mass index and other characteristics of heel pain. *J Foot Ankle Surg*. 2001;40(6):351-356. doi:10.1016/S1067-2516(01)80002-8.

37. Rathleff MS, Moelgaard C, Olesen JL. Intra- and interobserver reliability of quantitative ultrasound measurement of the plantar fascia. *J Clin Ultrasound*. 2011;39(3):128-134. doi:10.1002/jcu.20787.

38. Reb CW, Schick FA, Karanjia HN, Daniel JN. High prevalence of obesity and female gender among patients with concomitant tibialis posterior tendonitis and plantar fasciitis. *Foot Ankle Spec*. 2015;8(5):364-368. doi:10.1177/1938640015583511.

39. Riddle DL, Pulisic M, Pidcoe P, Johnson RE. Risk factors for plantar fasciitis: A matched case-control study. *J Bone Jt Surg*. 2003;85(5):872-877.

40. Riddle DL, Schappert SM. Volume of ambulatory care visits and patterns of care for patients diagnosed with plantar fasciitis: A national study of medical doctors. *Foot Ankle Int*. 2004;25(5):303-310.

41. Rosenbaum AJ, DiPreta JA, Misener D. Plantar heel pain. *Med Clin North Am*. 2014;98(2):339-352. doi:10.1016/j.mcna.2013.10.009.

42. Sabir N, Demirlenk S, Yagci B, Karabulut N, Cubukcu S. Clinical utility of sonography in diagnosing plantar fasciitis. *J Ultrasound Med*. 2005;24(8):1041-1048. doi:24/8/1041 [pii].

43. Scher DL, Belmont PJ, Bear R, Mountcastle SB, Orr JD, Owens BD. The incidence of plantar fasciitis in the United States military. *J Bone Joint Surg Am*. 2009;91(12):2867-2872. doi:10.2106/JBJS.I.00257.

44. Singh D, Angel J, Bentley G, Trevino SG. Plantar fasciitis. *BMJ*. 1997;315(July):172-175.

45. Taş S. Effect of gender on mechanical properties of the plantar fascia and heel fat pad. *Foot Ankle Spec*. 2017. doi:10.1177/1938640017735891.

46. Taş S, Bek N, Ruhi Onur M, Korkusuz F. Effects of Body Mass Index on Mechanical Properties of the Plantar Fascia and Heel Pad in Asymptomatic Participants. *Foot Ankle Int*. 2017;38(7):779-784. doi:10.1177/1071100717702463.

47. Taunton J, Ryan MB, Clement D, McKenzie D, Lloyd-Smith D, Zumbo B. A retrospective case-control analysis of 2002 running injuries. *Br J Sport Med*. 2002;36:95-101.

48. Tong KB, Furia J. Economic burden of plantar fasciitis treatment in the United States. *Am J Orthop*. 2010;39(5):227-231.

49. Tsai WC, Chiu MF, Wang CL, Tang FT, Wong MK. Ultrasound evaluation of plantar fasciitis. *Scand J Rheumatol*. 2000;29(4):255-259. doi:10.1080/030097400750041415.

50. Wall JR, Harkness MA, Crawford A. Ultrasound diagnosis of plantar fasciitis. *Foot Ankle Int*. 1993;14(8):465-470. doi:10.1177/107110079301400807.

51. Wearing SC, Smeathers JE, Urry SR, Hennig EM, Hills AP. The pathomechanics of plantar fasciitis. *Sport Med*. 2006;36(7):585-611. doi:10.2165/00007256-200636070-00004.

52. Wearing SC, Smeathers JE, Yates B, Sullivan PM, Urry SR, Dubois P. Sagittal movement of the medial longitudinal arch is unchanged in plantar fasciitis. *Med Sci Sports Exerc*. 2004;36(10):1761-1767. doi:10.1249/01.MSS.0000142297.10881.11.

53. Wolgin M, Cook C, Graham C, Mauldin D. Conservative treatment of plantar heel pain: long-term follow-up. *Foot Ankle Int*. 1994;15(3):97-102. doi:10.1177/107110079401500303.

CHAPTER FOUR

DISCUSSION

Since the first report of ultrasound being used to measure plantar fascia thickness was published in 1993,[48] ultrasound has become a widely used tool for visualizing the plantar fascia with accuracy levels comparable to MRI.[1,42] However, the lack of standardization of the MTP joints for measuring plantar fascia thickness with ultrasound has made make the results gathered from the procedure less reliable. Some of the of inconsistencies regarding plantar fascia thickness and its relationship to plantar fasciitis and gender have often been surrounded by conflicted results from similar studies. The main concept to ascertain from this study is that as MTP joints are extended, the plantar fascia decreases in thickness when observed during ultrasound. The current practice for measuring plantar fascia thickness via ultrasound does not involve a standardized position for the toes. Furthermore, the MTP joint position has varied in the literature depending on the preference of the examiner causing the thickness measurements to vary as well. Based upon the results from this study, the MTP joint position should be standardized during the ultrasound procedure, either at rest or at max extension to ensure ease of reproducibility. Although positioning the toes at rest is most likely the easiest position to reproduce and should be the established position when measuring plantar fascia thickness, some clinicians prefer to extend the toes in order to improve the border definition via ultrasound.[8,9,23,39,47] Thus, the authors recommend that the toes be at rest during an ultrasound plantar fascia thickness measurement and only at max MTP joint extension when improved visibility of the plantar fascia border is necessary. Finally, the

position of the MTP joints during the procedure should always be recorded to guarantee consistent protocols are followed in subsequent ultrasound measurements.

While the studies on plantar fascia thickness and gender have varied in the literature, the hope with standardizing MTP joint position would enable a more accurate comparison of plantar fascia thickness between males to females. From our study it was discovered that no significant difference in plantar fascia thickness existed between healthy males and females. However, gender differences were observed in the plantar fasciitis group, whereby males collectively had a significantly thicker plantar fascia when compared to females. The reasons for this are unclear although it has been suggested that the architecture and mechanical properties of the plantar fascia in women differ with that of men as a possible cause.[40] Furthermore, males with unilateral plantar fasciitis had significantly thicker asymptomatic plantar fasciae versus healthy control. The response in females was much less significant, lending support to males typically having a larger reaction to plantar fasciitis as far as plantar fascia thickness is concerned.

As well, males and females with plantar fasciitis had a different pattern of thickness change as MTP joints were extended. Males with plantar fasciitis tended to exhibit most of the decrease in plantar fascia thickness between the MTP joint positions of at rest and 30 degrees and then very little change from 30 degrees to max extension. In contrast, females with plantar fasciitis had a consistent level of change in plantar fascia thickness throughout the various MTP joint extension positions. If the majority of the elongation of the plantar fascia in males occurred between at rest and 30 degrees of MTP joint extension, then it could be hypothesized that the plantar fasciae in males with plantar fasciitis are able to resist elongation and tensile forces better than females. It

could also be hypothesized that males reach the elongation limit much earlier than females because the predominant mechanism for males with plantar fasciitis is due to tissue tightness and/or a lack of flexibility (i.e., gastroc-soleus, tendoachilles). In contrast, the results observed in females were possibly due to having more tissue elasticity pointing to the possibility that the predominant mechanism of plantar fasciitis in women has less to do with tissue tightness and more to do a lack of strength within the kinetic chain (e.g., muscle, tendon, fascia). Ultimately, this may foreshadow how gender could play a role in the treatment planning for those with plantar fasciitis, and even change our view of increased plantar fascia thickness as actually a protective mechanism for avoiding pain and other symptoms associated with plantar fasciitis.

Conclusions and Future Directions

The results from this study demonstrated that MTP joint extension was able to decrease ultrasound thickness measurements of the plantar fascia. Due to ultrasound examiners varying the MTP joint position during the procedure, the reliability of plantar fascia thickness measurements can become compromised. This highlights the need to consider and standardize the MTP joint position during plantar fascia thickness measurements in order to acquire the most accurate and reliable results. Future studies utilizing MRI to visualize the plantar fascia while MTP joints are undergoing extension would be of strong interest as it could corroborate what was observed in this study.

A comparison of plantar fascia thickness measurements between males and females was conducted with the MTP joint position standardized. Healthy males and females were found to have no significant differences in terms of plantar fascia thickness.

However, males with plantar fasciitis were found to have thicker plantar fasciae than their female counterparts. Males also had significantly thicker plantar fascia on the involved side when compared to the uninvolved side, an observation to a lesser degree was also observed in females.

Lastly, males tended to exhibit most of the decrease in the plantar fascia thickness when the MTP joints were extended from at rest to 30°, with very little change occurring between 30° to max. Females, on the other hand, had a relatively constant decrease in plantar fascia thickness throughout the entire range the MTP joints were extended from at rest to max. If the pattern of decrease in plantar fascia thickness in males was more so indicative of a lack of flexibility in males, future studies could possibly examine the effectiveness of emphasizing certain treatment options for plantar fasciitis that consider gender, such as stretching and joint mobilization being emphasized more so with males.

REFERENCES

1. Abdel-Wahab N, Fathi S, Al-Emadi S, Mahdi S. High-resolution ultrasonographic diagnosis of plantar fasciitis: a correlation of ultrasound and magnetic resonance imaging. Int J Rheum Dis. 2008;11:279-286.

2. Abul K, Ozer D, Sakizlioglu SS, Buyuk AF, Kaygusuz MA. Detection of normal plantar fascia thickness in adults via the ultrasonographic method. J Am Podiatr Med Assoc. 2015;105(1):8-13. doi:10.7547/8750-7315-105.1.8.

3. Akfirat M, Sen C, Günes T. Ultrasonographic appearance of the plantar fasciitis. Clin Imaging. 2003;27(5):353-357. doi:10.1016/S0899-7071(02)00591-0.

4. Barrett S, O'Malley R. Plantar fasciitis and other causes of heel pain. Am Fam Physician. 1999;59(8):2200-2206.

5. Bartold SJ. The plantar fascia as a source of pain - Biomechanics, presentation and treatment. J Bodyw Mov Ther. 2004;8(3):214-226. doi:10.1016/S1360-8592(03)00087-1.

6. Beggs I, Bianchi S, Bueno A, et al. Musculoskeletal ultrasound technical guidelines (VI. Ankle). https://essr.org/content-essr/uploads/2016/10/ankle.pdf. Published 2010. Accessed January 15, 2018.

7. Bertakis KD, Azari R, Callahan EJ, Robbins JA. Gender Differences in the Utilization of Health care Services. J Fam Pract. 2000;49(2):147-152.

8. Bisi-Balogun A, Cassel M, Mayer F. Reliability of various measurement stations for determining plantar fascia thickness and echogenicity. Diagnostics. 2016;6(2):15. doi:10.3390/diagnostics6020015.

9. Cardinal E, Chhem RK, Beauregard CG, Aubin B, Pelletier M. Plantar fasciitis: sonographic evaluation. Radiology. 1996;201(1):257-259. doi:10.1148/radiology.201.1.8816554.

10. Carlson RE, Fleming LL, Hutton WC. The biomechanical relationship between the tendoachilles, plantar fascia and metatarsophalangeal joint dorsiflexion angle. Foot Ankle Int. 2000;21(1):18-25. doi:10.1177/107110070002100104.

11. Cheng HYK, Lin CL, Chou SW, Wang HW. Nonlinear finite element analysis of the plantar fascia due to the windlass mechanism. Foot Ankle Int. 2008;29(8):845-851. doi:10.3113/FAI.2008.0845.

12. Cheng HYK, Lin CL, Wang HW, Chou SW. Finite element analysis of plantar fascia under stretch-The relative contribution of windlass mechanism and Achilles tendon force. J Biomech. 2008;41(9):1937-1944. doi:10.1016/j.jbiomech.2008.03.028.

13. Crawford F, Thomson CE. Interventions for treating plantar heel pain. Cochrane

Database Syst Rev. 2003;3(3):CD000416. doi:10.1002/14651858.CD000416.

14. Davis PF, Severud E, Baxter DE. Painful heel syndrome: Results of nonoperative treatment. Foot Ankle Int. 1994;15(10):531-535. doi:10.1177/107110079401501002.

15. DeMaio M, Paine R, Mangine RE, Drez D. Plantar Fasciitis. Orthopedics. 1993;16(10):1155-1163. doi:10.3928/0147-7447-19931001-13.

16. Fraser JJ, Glaviano NR, Hertel J. Utilization of physical therapy intervention among patients with plantar fasciitis in the United States. J Orthop Sport Phys Ther. 2017;47(2):49-55. doi:10.2519/jospt.2017.6999.

17. Gadalla N, Kichouh M, Boulet C, Machiels F, De Mey J, De Maeseneer M. Sonographic evaluation of the plantar fascia in asymptomatic subjects. Jbr-Btr. 2014;97(5):271-273.

18. Garcia CA, Hoffman SL, Hastings MK, Klaesner JW, Mueller MJ. Effect of metatarsal phalangeal joint extension on plantar soft tissue stiffness and thickness. Foot. 2008;18(2):61-67. doi:10.1016/j.foot.2007.12.002.

19. Genc H, Saracoglu M, Nacir B, Erdem HR, Kacar M. Long-term ultrasonographic follow-up of plantar fasciitis patients treated with steroid injection. Jt Bone Spine. 2005;72(1):61-65. doi:10.1016/j.jbspin.2004.03.006.

20. Gibbon W. Plantar fasciitis: US imaging (letter). Radiology. 1992;182(1):285.

21. Hansen L, Krogh TP, Ellingsen T, Bolvig L, Fredberg U. Long-term prognosis of plantar fasciitis: A 5- to 15-year follow-up study of 174 patients with ultrasound examination. Orthop J Sport Med. 2018;6(3):1-9. doi:10.1177/2325967118757983.

22. Hill CL, Gill TK, Menz HB, Taylor AW. Prevalence and correlates of foot pain in a population-based study: The North West Adelaide health study. J Foot Ankle Res. 2008;1(2). doi:10.1186/1757-1146-1-2.

23. Huerta JP, Garcia JMA. Effect of gender, age and anthropometric variables on plantar fascia thickness at different locations in asymptomatic subjects. Eur J Radiol. 2007;62(3):449-453. doi:10.1016/j.ejrad.2007.01.002.

24. Huerta JP, García JMA, Matamoros EC, Matamoros JC, Martínez TD. Relationship of body mass index, ankle dorsiflexion, and foot pronation on plantar fascia thickness in healthy, asymptomatic subjects. J Am Podiatr Med Assoc. 2008;98(5):379-385. doi:10.7547/0980379.

25. Kappel-Bargas A, Woolf RD, Cornwall MW, McPoil TG. The windlass mechanism during normal walking and passive first metatarsalphalangeal joint extension. Clin Biomech. 1998;13(3):190-194. doi:10.1016/S0268-0033(97)00038-7.

26. Karabay N, Toros T, Hurel C. Ultrasonographic evaluation in plantar fasciitis. J Foot

Ankle Surg. 2007;46(6):442-446. doi:10.1053/j.jfas.2007.08.006.

27. Kibler WB, Goldberg C, Chandler TJ. Functional biomechanical deficits in running athletes with plantar fasciitis. Am J Sports Med. 1991;19(1):66-71. doi:10.1177/036354659101900111.

28. Klein SE, Dale AM, Hayes MH, Johnson JE, McCormick JJ, Racette BA. Clinical presentation and self-reported patterns of pain and function in patients with plantar heel pain. Foot Ankle Int. 2012;33(9):693-698. doi:10.3113/FAI.2012.0693.

29. Lapidus P, Guidotti F. Painful heel: Report of 323 patients with 364 painful heels. Clin Orthop Relat Res. 1965;39:178-186.

30. League AC. Current concepts review: Plantar fasciitis. Foot Ankle Int. 2008;29(3):358-366. doi:10.3113/FAI.2008.0358.

31. Lee SY, Park HJ, Kwag HJ, et al. Ultrasound elastography in the early diagnosis of plantar fasciitis. Clin Imaging. 2014;38(5):715-718. doi:10.1016/j.clinimag.2012.12.004.

32. Lemont H, Ammirati KM, Usen N. Plantar fasciitis. J Am Podiatr Med Assoc. 2003;93(3):234-237. doi:10.7547/87507315-93-3-234.

33. McMillan AM, Landorf KB, Barrett JT, Menz HB, Bird AR. Diagnostic imaging for chronic plantar heel pain: a systematic review and meta-analysis. J Foot Ankle Res. 2009;2:32. doi:10.1186/1757-1146-2-32.

34. McNally EG, Shetty S. Plantar fascia: Imaging diagnosis and guided treatment. Semin Musculoskelet Radiol. 2010;14(3):334-343. doi:10.1055/s-0030-1254522.

35. Mohseni-Bandpei MA, Nakhaee M, Mousavi ME, Shakourirad A, Safari MR, Vahab Kashani R. Application of ultrasound in the assessment of plantar fascia in patients with plantar fasciitis: A systematic review. Ultrasound Med Biol. 2014;40(8):1737-1754. doi:10.1016/j.ultrasmedbio.2014.03.001.

36. Mølgaard C, Lundbye-Christensen S, Simonsen O. High prevalence of foot problems in the Danish population: A survey of causes and associations. Foot. 2010;20(1):7-11. doi:10.1016/j.foot.2010.03.002.

37. Ozdemir H, Yilmaz E, Murat A, Karakurt L, Poyraz AK, Ogur E. Sonographic evaluation of plantar fasciitis and relation to body mass index. Eur J Radiol. 2005;54(3):443-447. doi:10.1016/j.ejrad.2004.09.004.

38. Rano JA, Fallat LM, Savoy-Moore RT. Correlation of heel pain with body mass index and other characteristics of heel pain. J Foot Ankle Surg. 2001;40(6):351-356. doi:10.1016/S1067-2516(01)80002-8.

39. Rathleff MS, Moelgaard C, Olesen JL. Intra- and interobserver reliability of

quantitative ultrasound measurement of the plantar fascia. J Clin Ultrasound. 2011;39(3):128-134. doi:10.1002/jcu.20787.

40. Reb CW, Schick FA, Karanjia HN, Daniel JN. High prevalence of obesity and female gender among patients with concomitant tibialis posterior tendonitis and plantar fasciitis. Foot Ankle Spec. 2015;8(5):364-368. doi:10.1177/1938640015583511.

41. Riddle DL, Pulisic M, Pidcoe P, Johnson RE. Risk factors for plantar fasciitis: A matched case-control study. J Bone Jt Surg. 2003;85(5):872-877.

42. Sabir N, Demirlenk S, Yagci B, Karabulut N, Cubukcu S. Clinical utility of sonography in diagnosing plantar fasciitis. J Ultrasound Med. 2005;24(8):1041-1048. doi:24/8/1041 [pii].

43. Scher DL, Belmont PJ, Bear R, Mountcastle SB, Orr JD, Owens BD. The incidence of plantar fasciitis in the United States military. J Bone Joint Surg Am. 2009;91(12):2867-2872. doi:10.2106/JBJS.I.00257.

44. Singh D, Angel J, Bentley G, Trevino SG. Plantar fasciitis. BMJ. 1997;315(July):172-175.

45. Taş S. Effect of gender on mechanical properties of the plantar fascia and heel fat pad. Foot Ankle Spec. 2017. doi:10.1177/1938640017735891.

46. Taunton J, Ryan MB, Clement D, McKenzie D, Lloyd-Smith D, Zumbo B. A retrospective case-control analysis of 2002 running injuries. Br J Sport Med. 2002;36:95-101.

47. Tsai WC, Chiu MF, Wang CL, Tang FT, Wong MK. Ultrasound evaluation of plantar fasciitis. Scand J Rheumatol. 2000;29(4):255-259. doi:10.1080/030097400750041415.

48. Wall JR, Harkness MA, Crawford A. Ultrasound diagnosis of plantar fasciitis. Foot Ankle Int. 1993;14(8):465-470. doi:10.1177/107110079301400807.

49. Wearing SC, Smeathers JE, Sullivan PM, Yates B, Urry SR, Dubois P. Plantar fasciitis: Are pain and fascial thickness associated with arch shape and loading? Phys Ther. 2007;87(8):1002-1008. doi:10.2522/ptj.20060136.

50. Wearing SC, Smeathers JE, Urry SR, Hennig EM, Hills AP. The pathomechanics of plantar fasciitis. Sport Med. 2006;36(7):585-611. doi:10.2165/00007256-200636070-00004.

51. Wearing SC, Smeathers JE, Yates B, Sullivan PM, Urry SR, Dubois P. Sagittal movement of the medial longitudinal arch is unchanged in plantar fasciitis. Med Sci Sports Exerc. 2004;36(10):1761-1767. doi:10.1249/01.MSS.0000142297.10881.11.